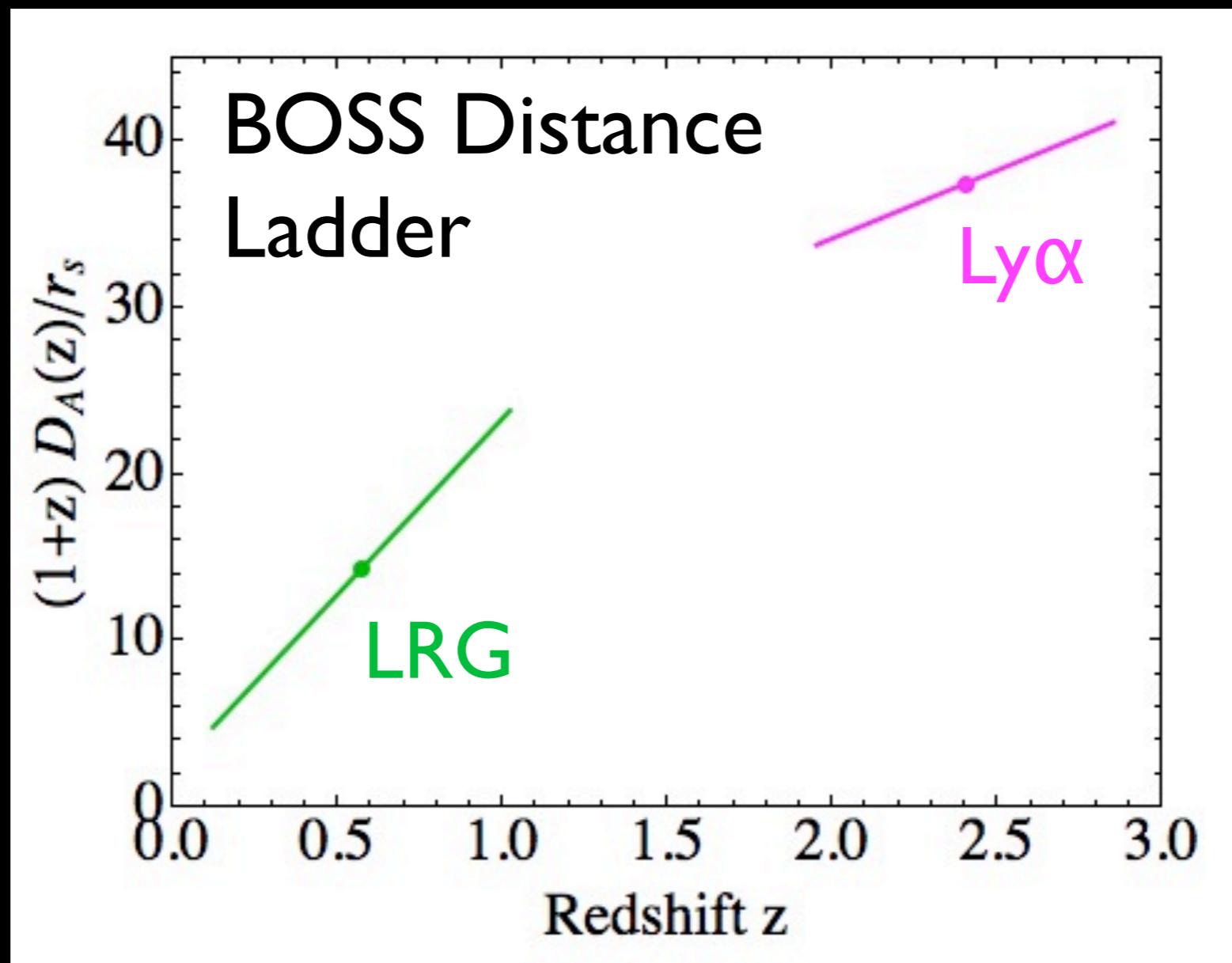


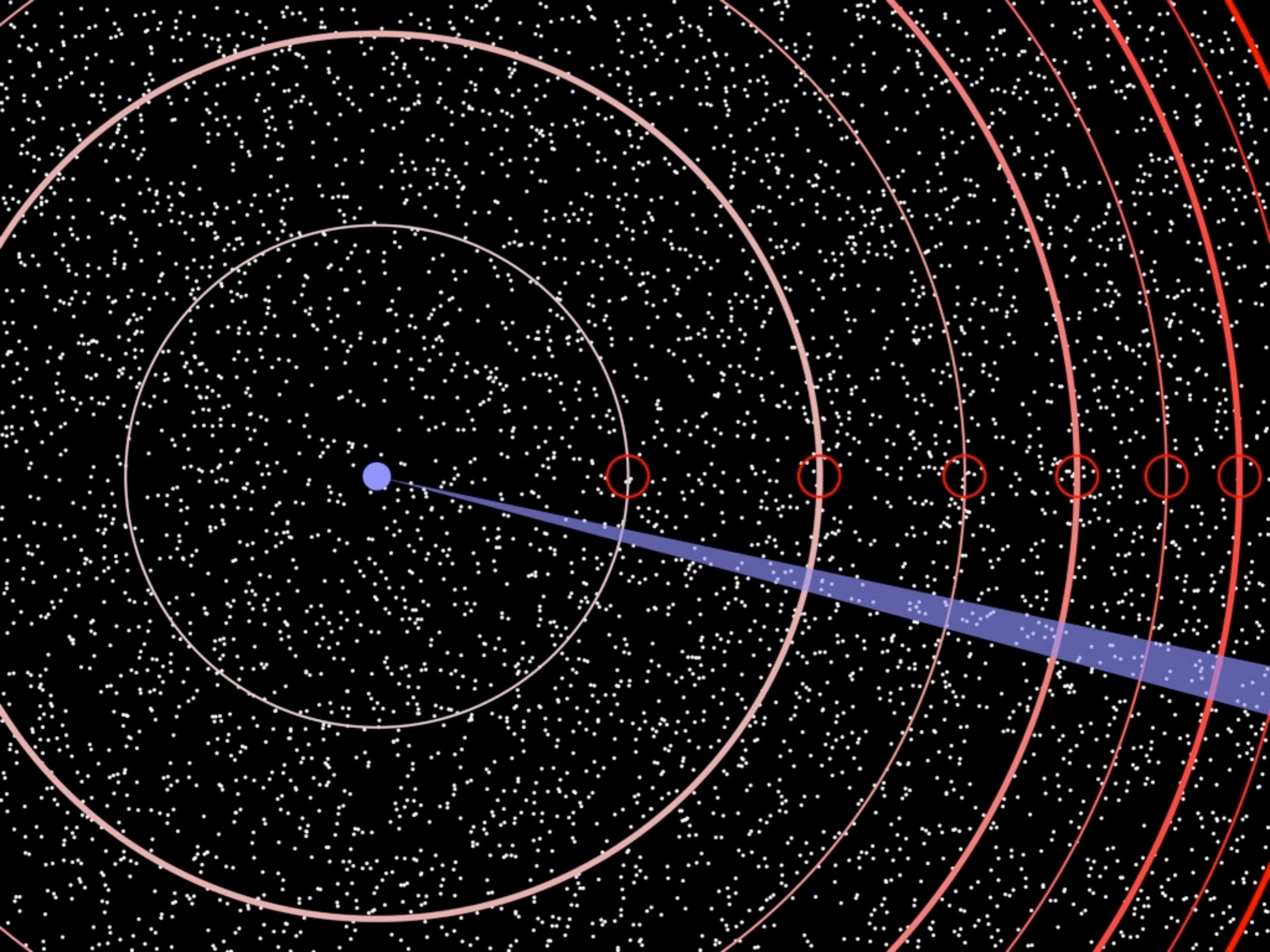
# BOSS Science: 3D BAO

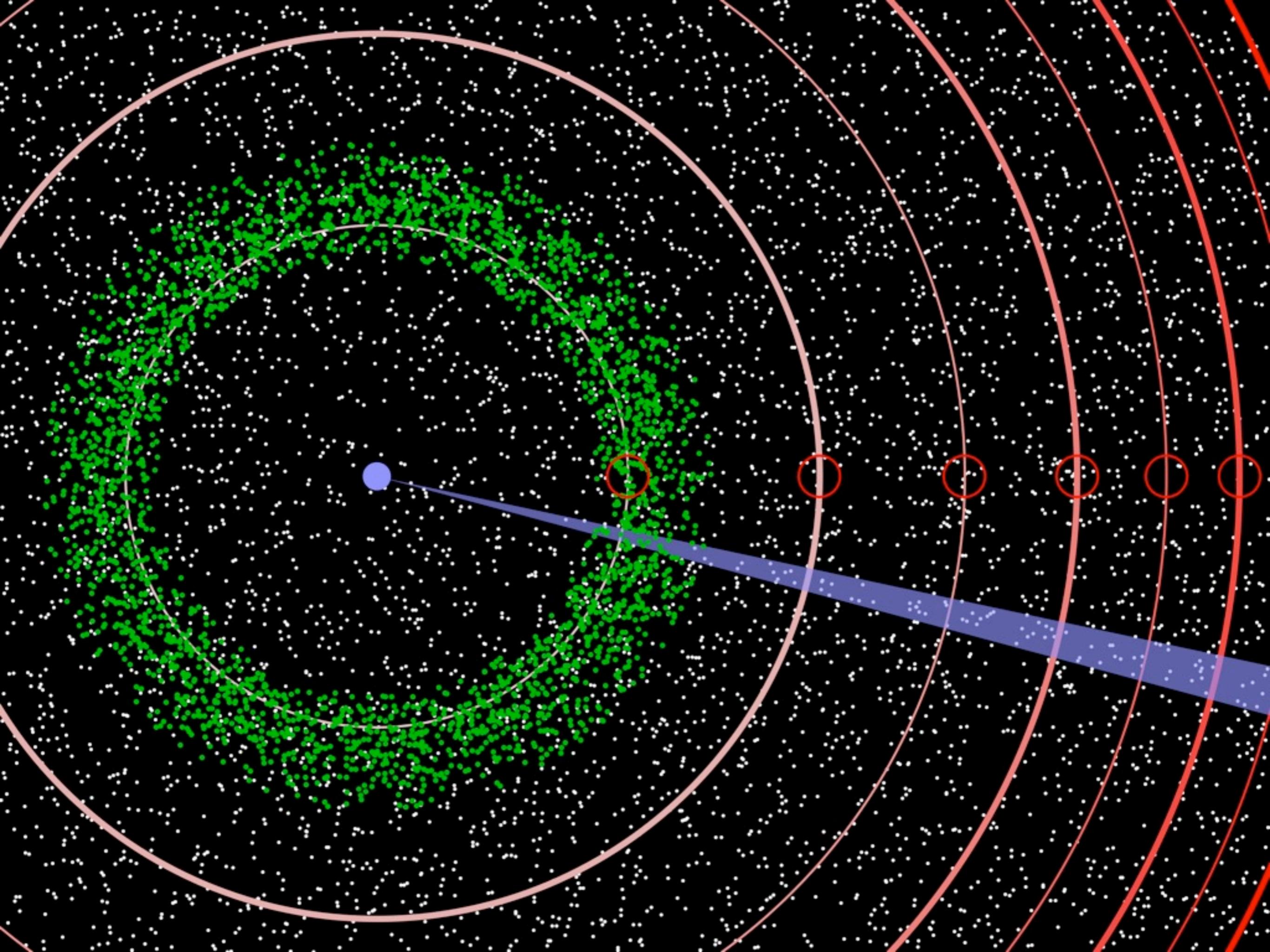
*David Kirkby, UC Irvine / CEA Saclay*

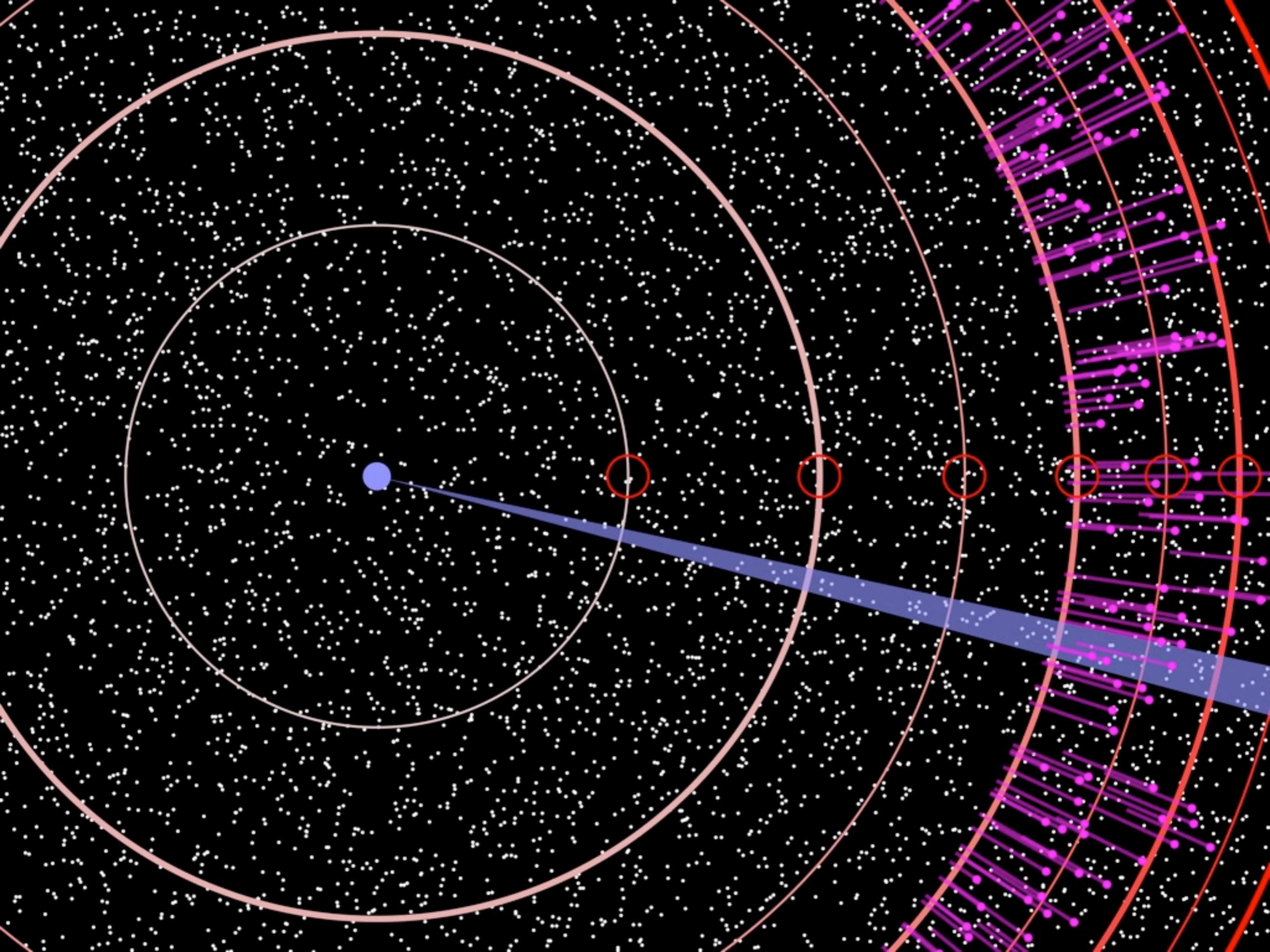
MS-DESI Meeting @ LBNL  
5 March 2013

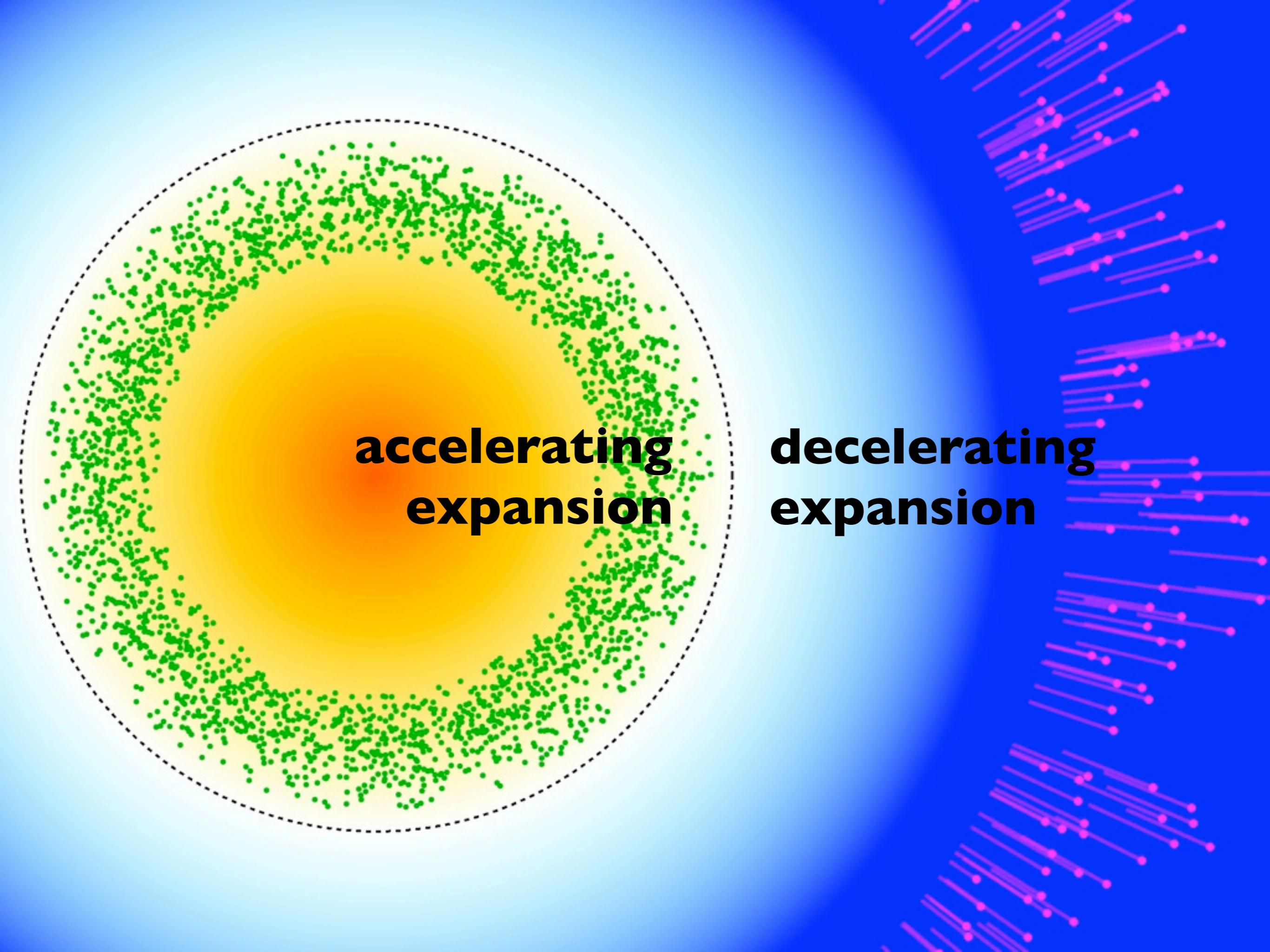
# BOSS Science: 3D BAO







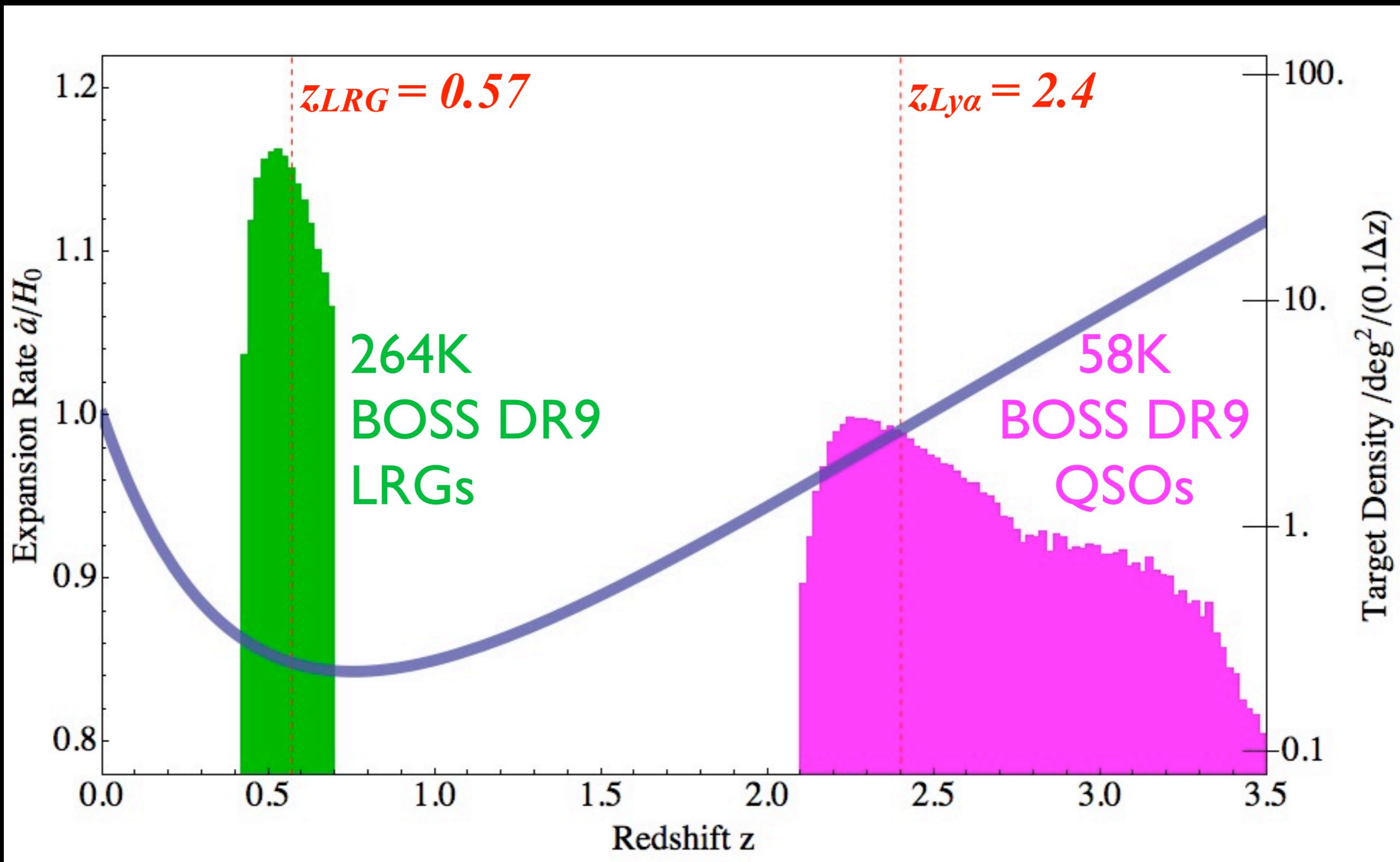


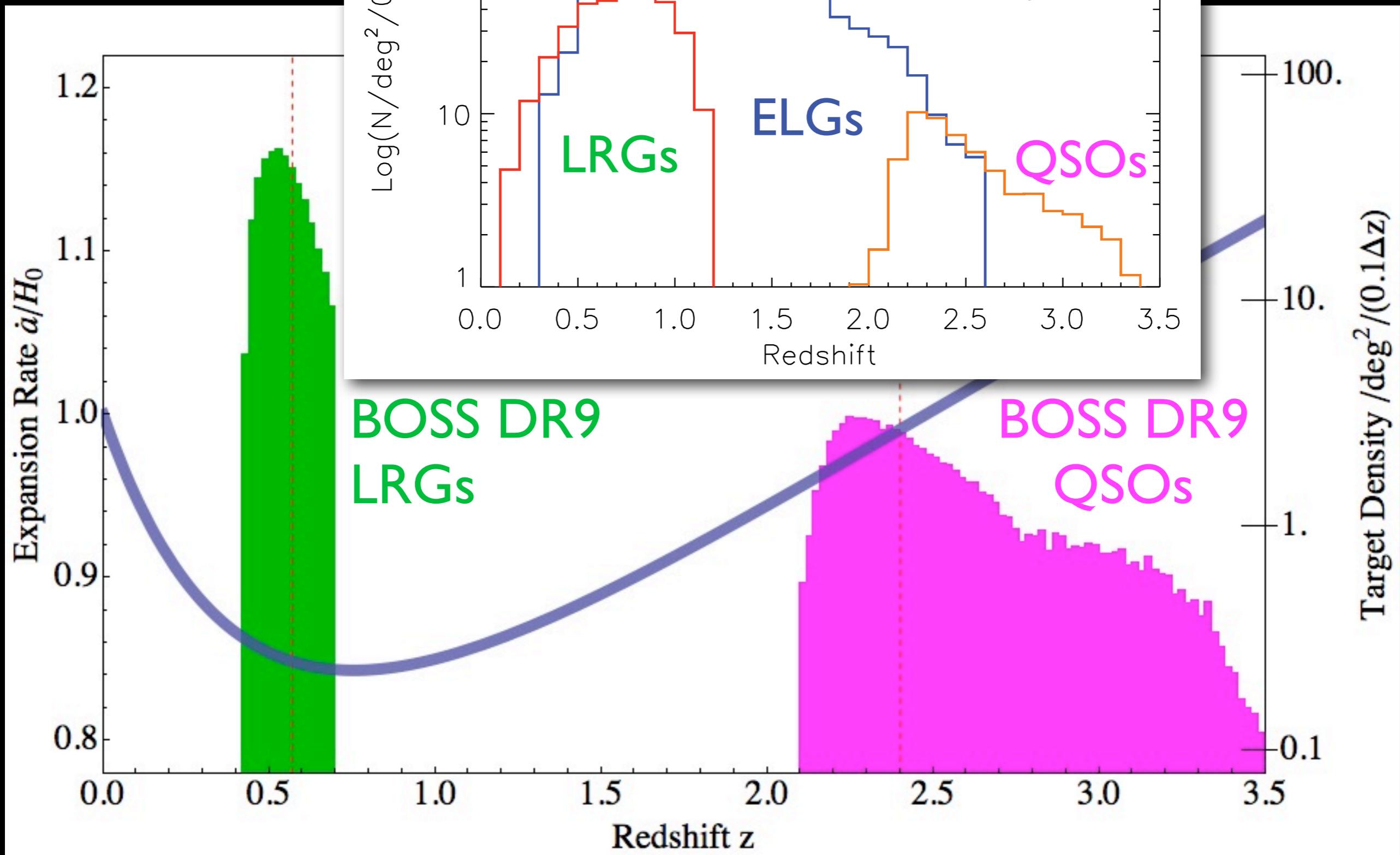


**accelerating  
expansion**

**decelerating  
expansion**

# BOSS DR9 Samples





$$\Delta r_{\parallel} = \frac{c}{H(z)} \Delta z$$

observer



$$\Delta r_{\parallel} = \frac{c}{H(z)} \Delta z$$

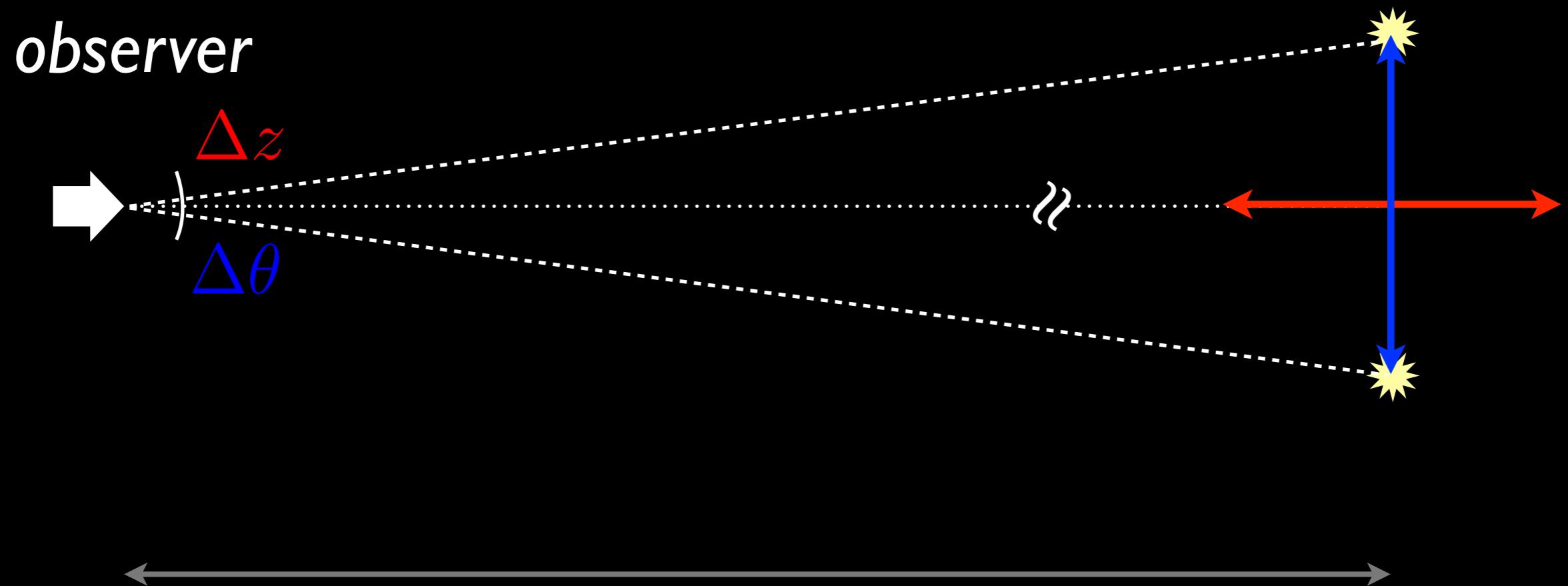
observer



$$r_{\parallel}(z) = \int_0^z \frac{c}{H(z')} dz'$$

$$\Delta r_{\parallel} = \frac{c}{H(z)} \Delta z$$

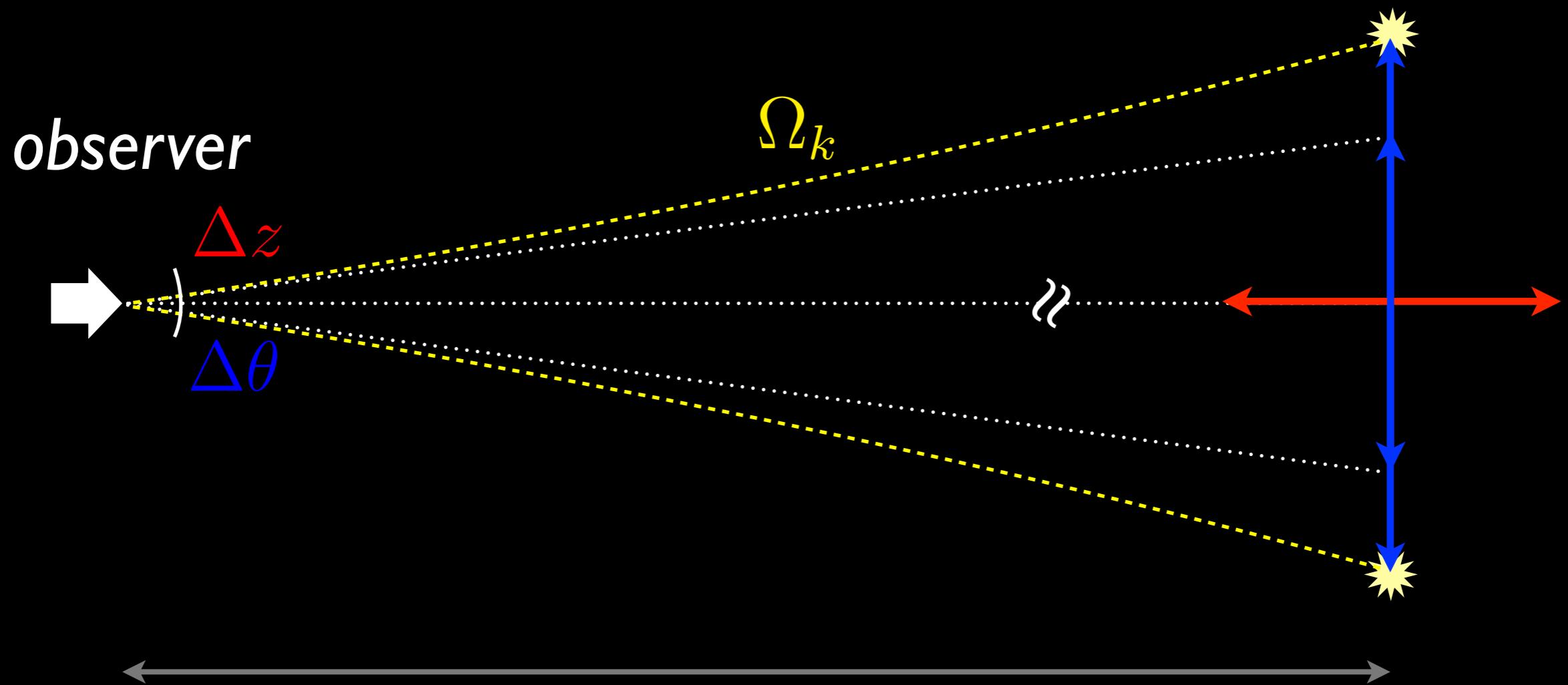
$$\Delta r_{\perp} = r_{\parallel}(z) \Delta \theta$$



$$r_{\parallel}(z) = \int_0^z \frac{c}{H(z')} dz'$$

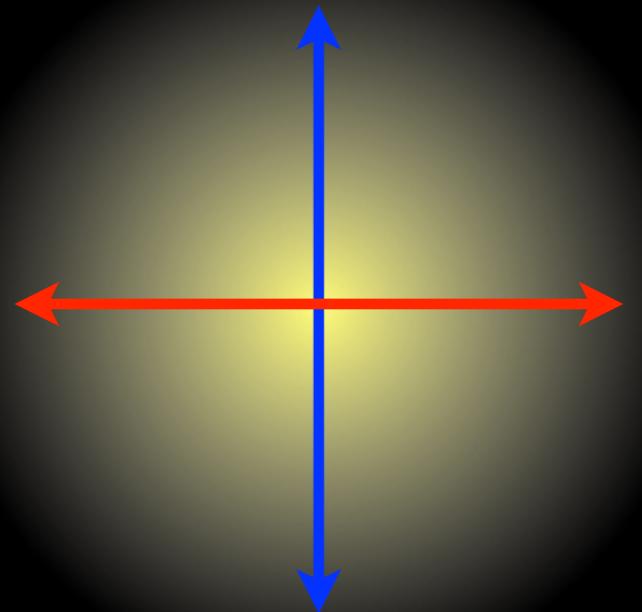
$$\Delta r_{\parallel} = \frac{c}{H(z)} \Delta z$$

$$\Delta r_{\perp} = (1+z) D_A(z) \Delta \theta$$

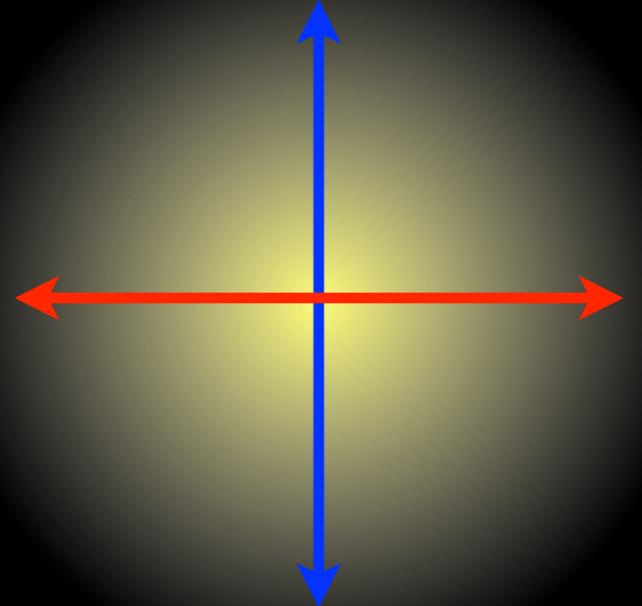


$$r_{\parallel}(z) = \int_0^z \frac{c}{H(z')} dz'$$

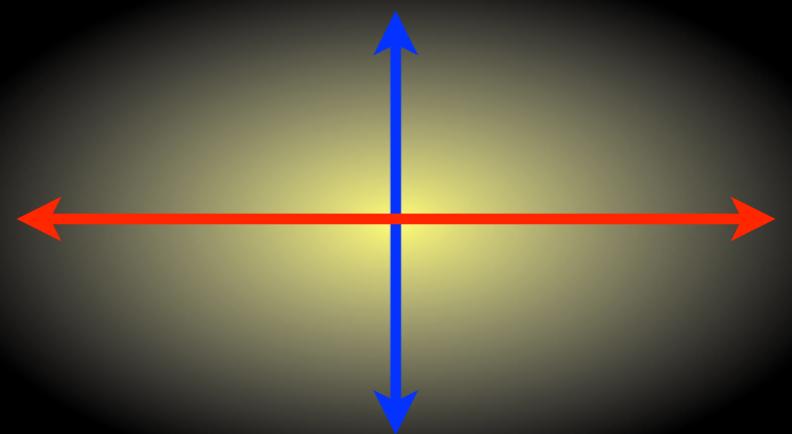
if a large-scale correlation is  
isotropic in true cosmology...



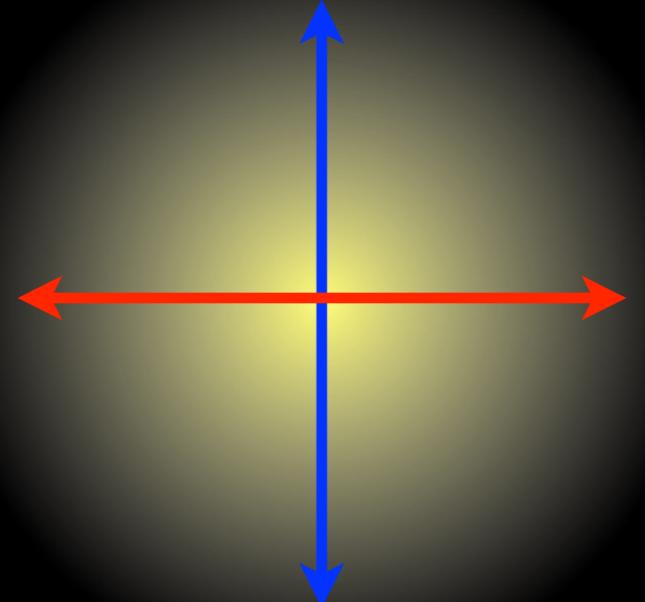
if a large-scale correlation is  
isotropic in true cosmology...



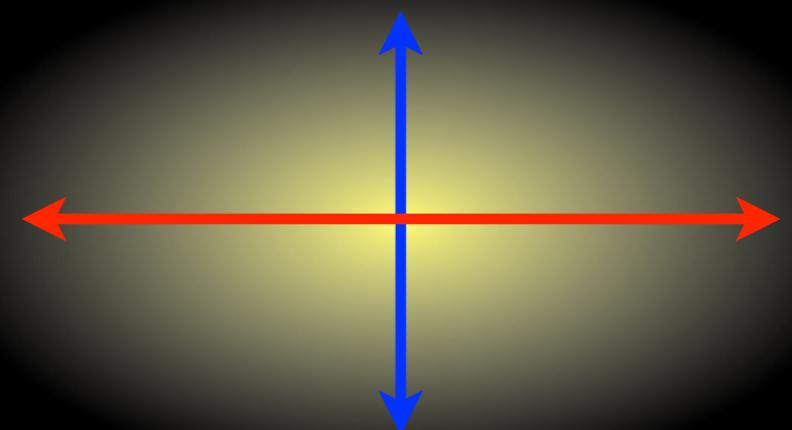
...but observed to be anisotropic  
in assumed fiducial cosmology...



if a large-scale correlation is isotropic in true cosmology...



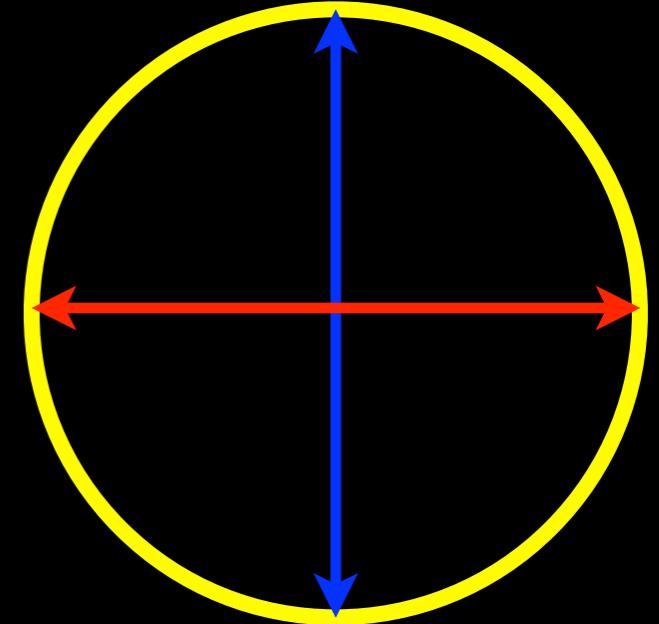
...but observed to be anisotropic in assumed fiducial cosmology...



...then can measure product  $D_A(z)H(z)/c$  needed to restore symmetry.

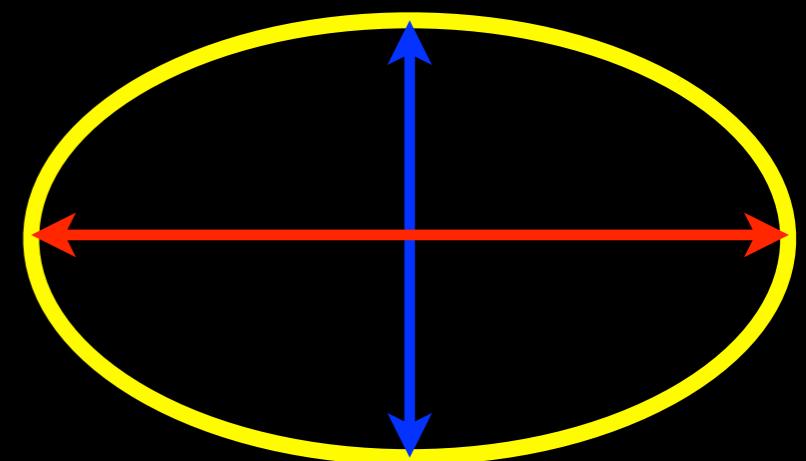
(Alcock-Paczynski effect)

if a large-scale correlation is isotropic in true cosmology...



...and of a known size  $r_s$ ...

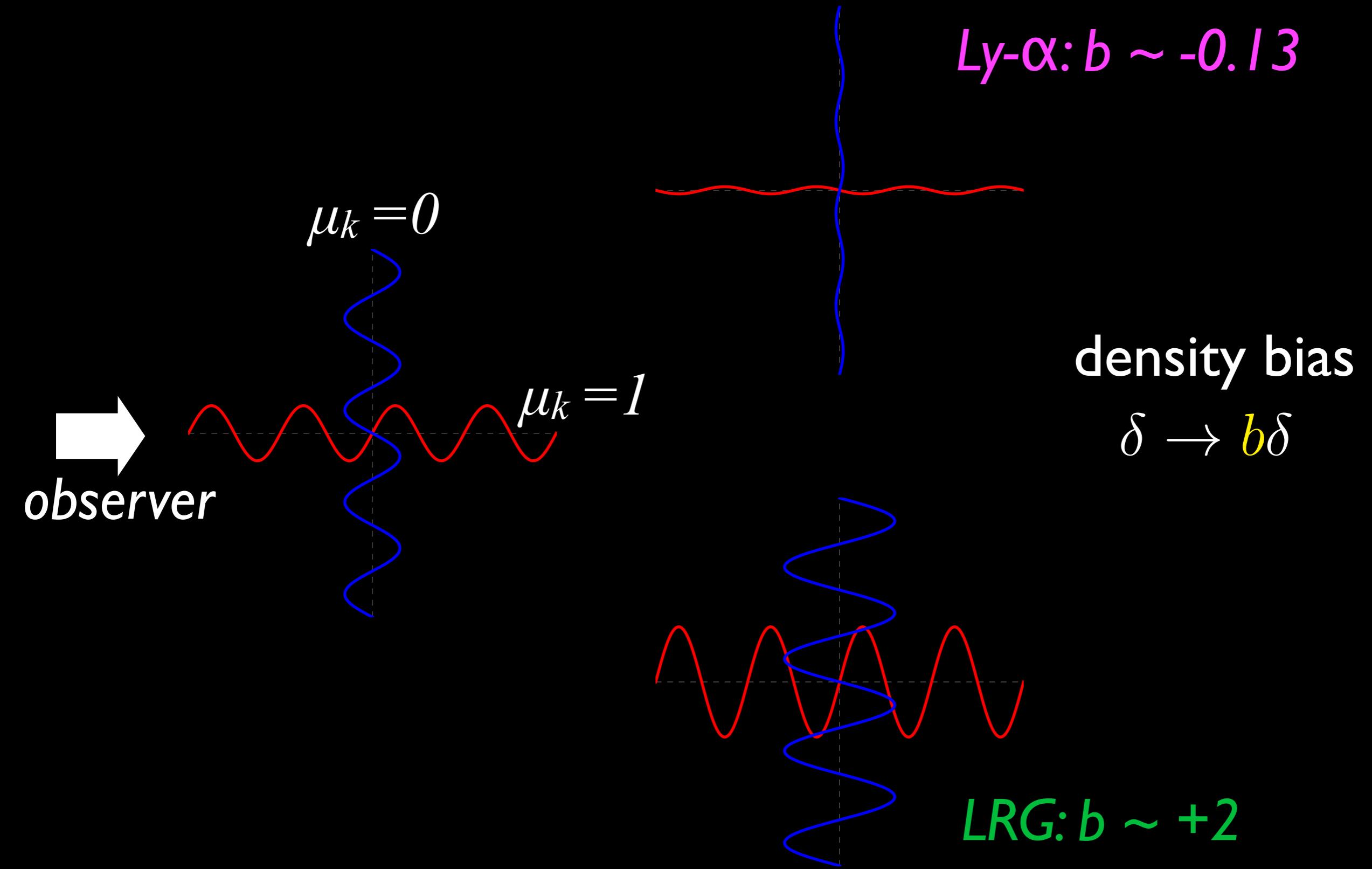
...but observed to be anisotropic in assumed fiducial cosmology...



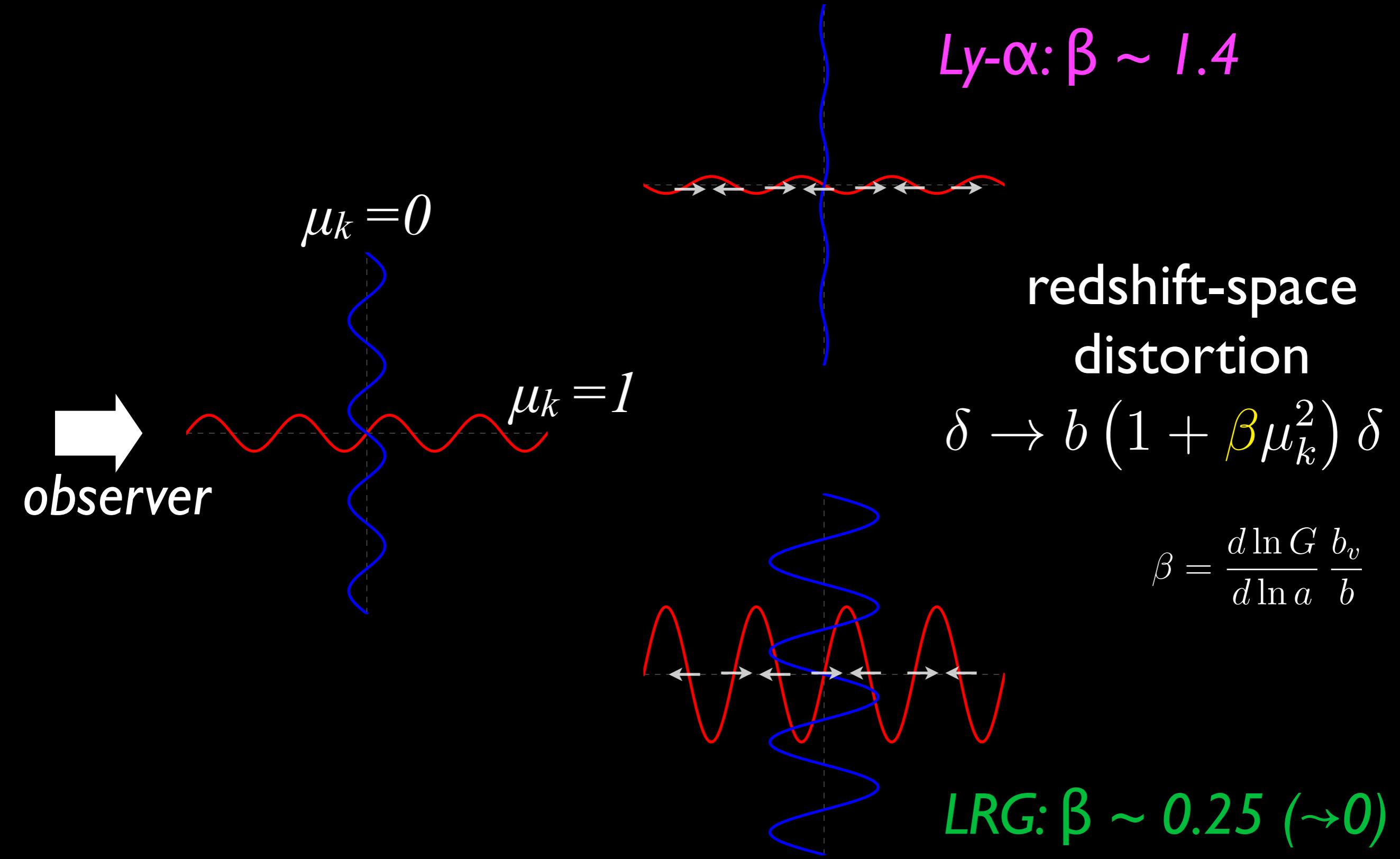
...then can measure  $D_A(z)/r_s$  and  $c/(r_s H(z))$  needed to restore symmetry and size.

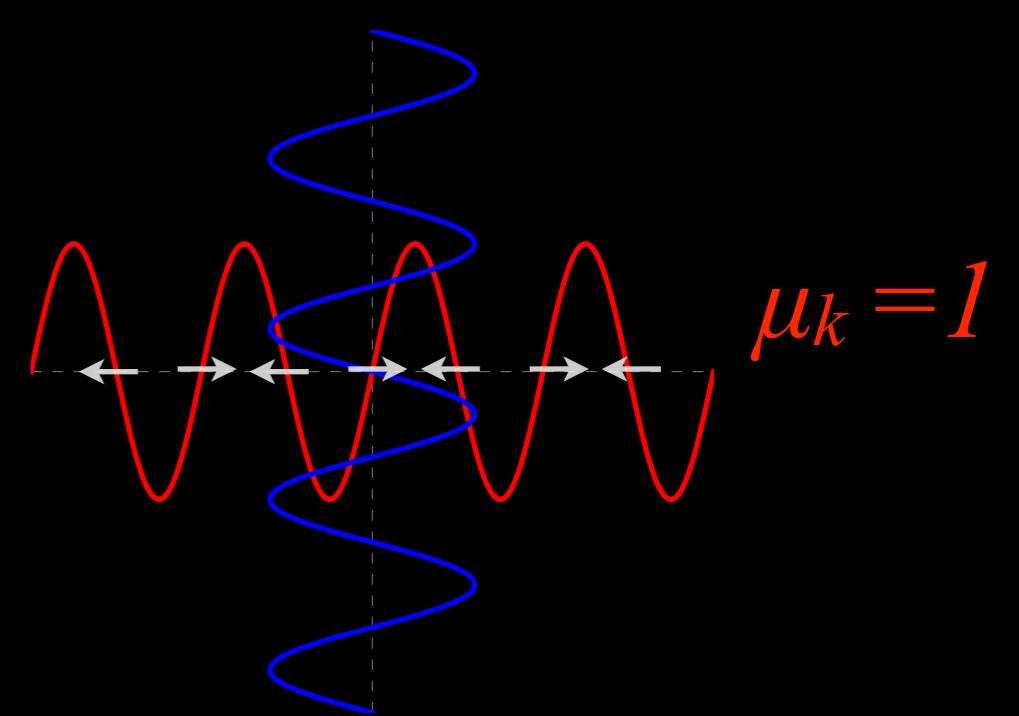
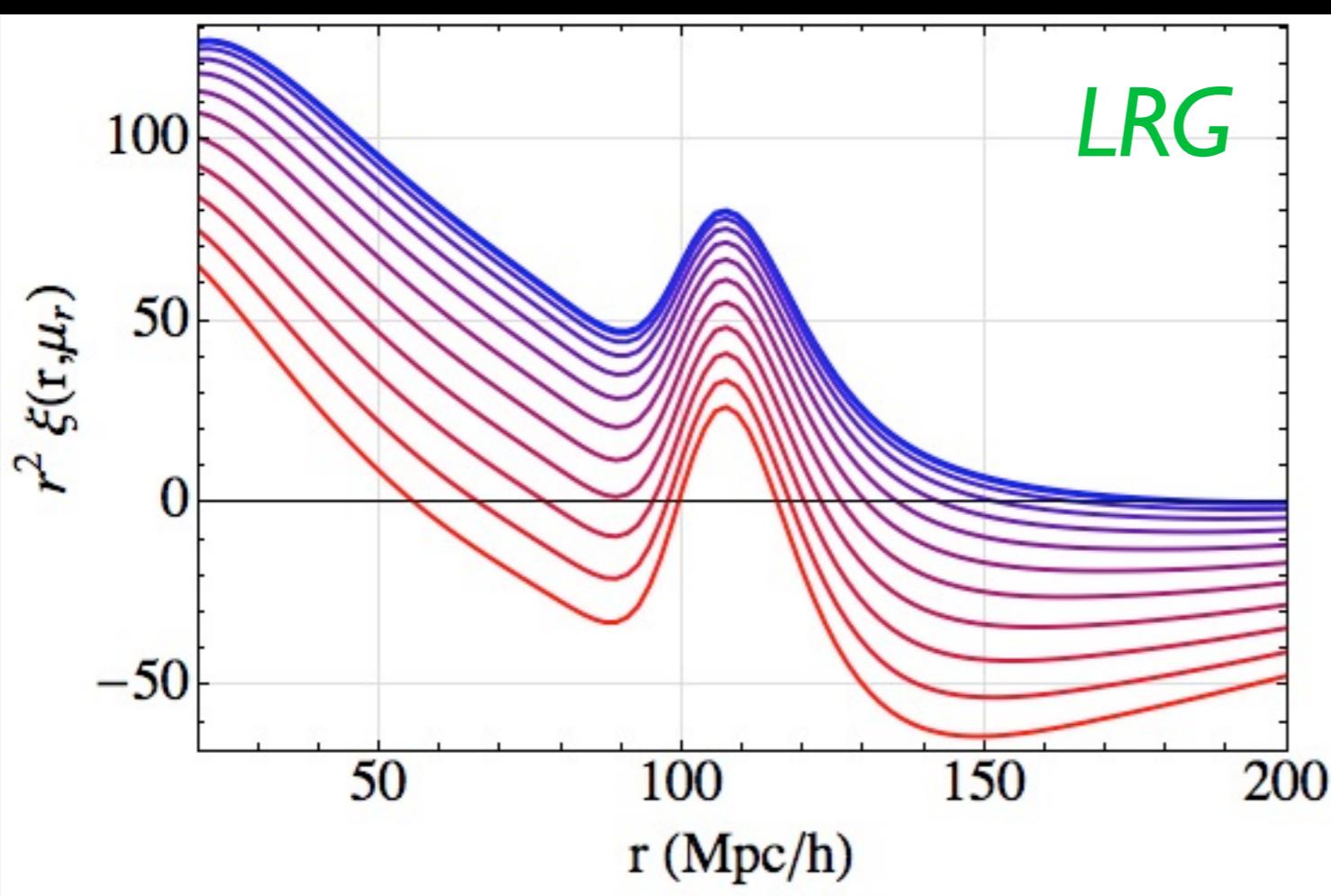
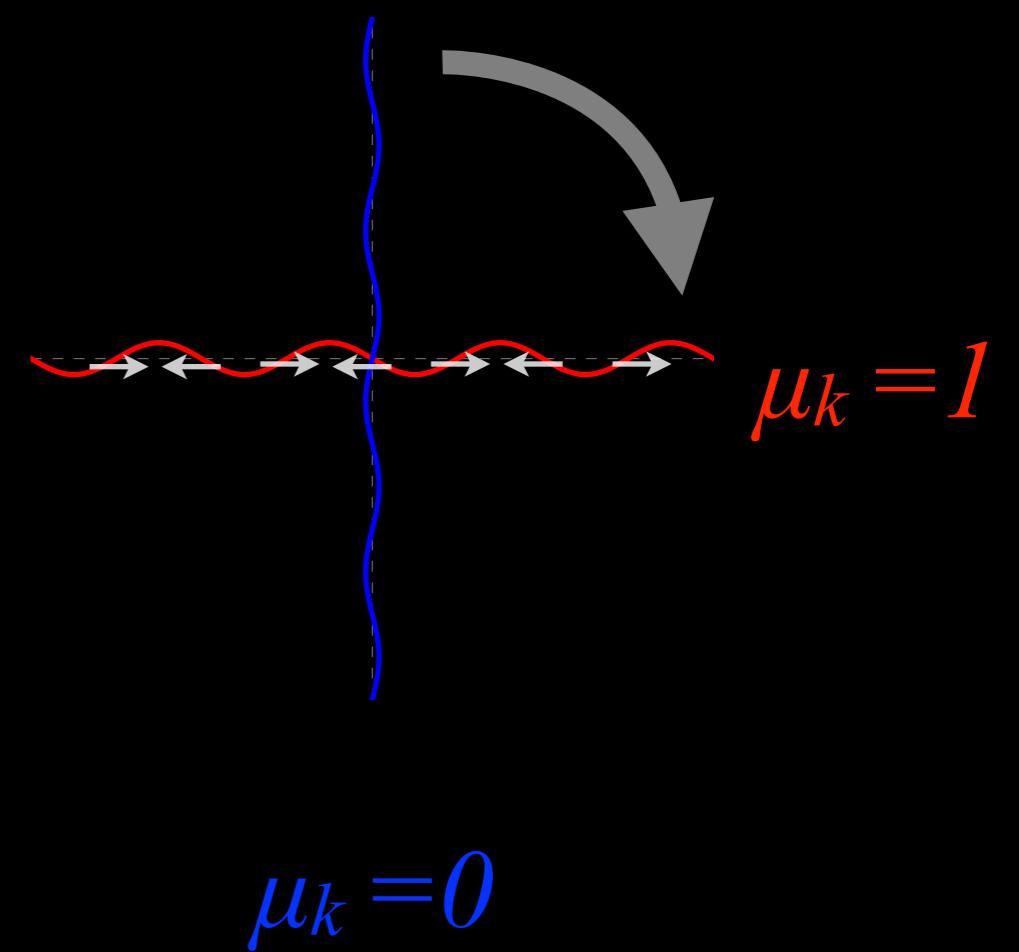
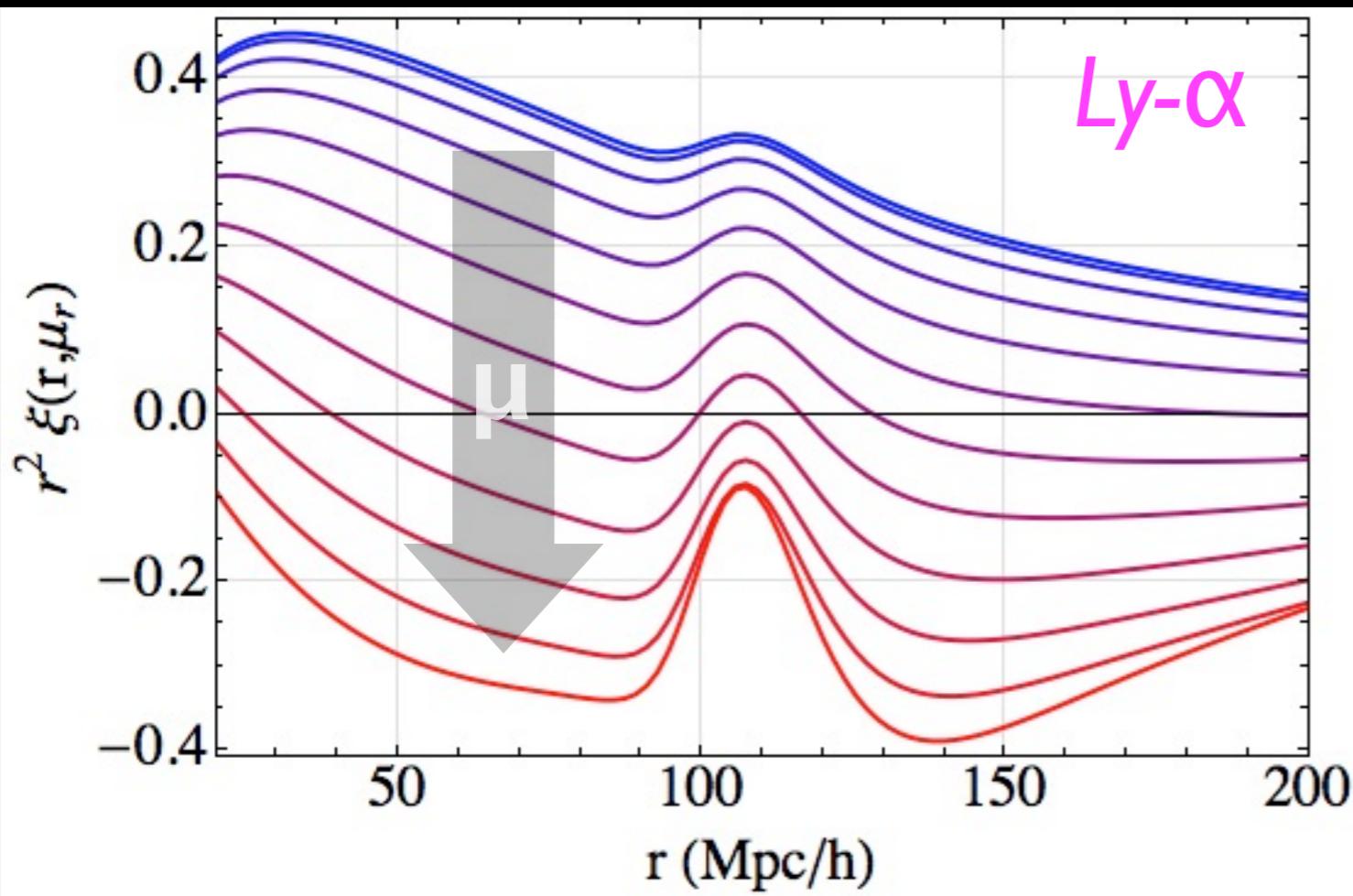
(Alcock-Paczynski effect)

# Redshift Space Distortions

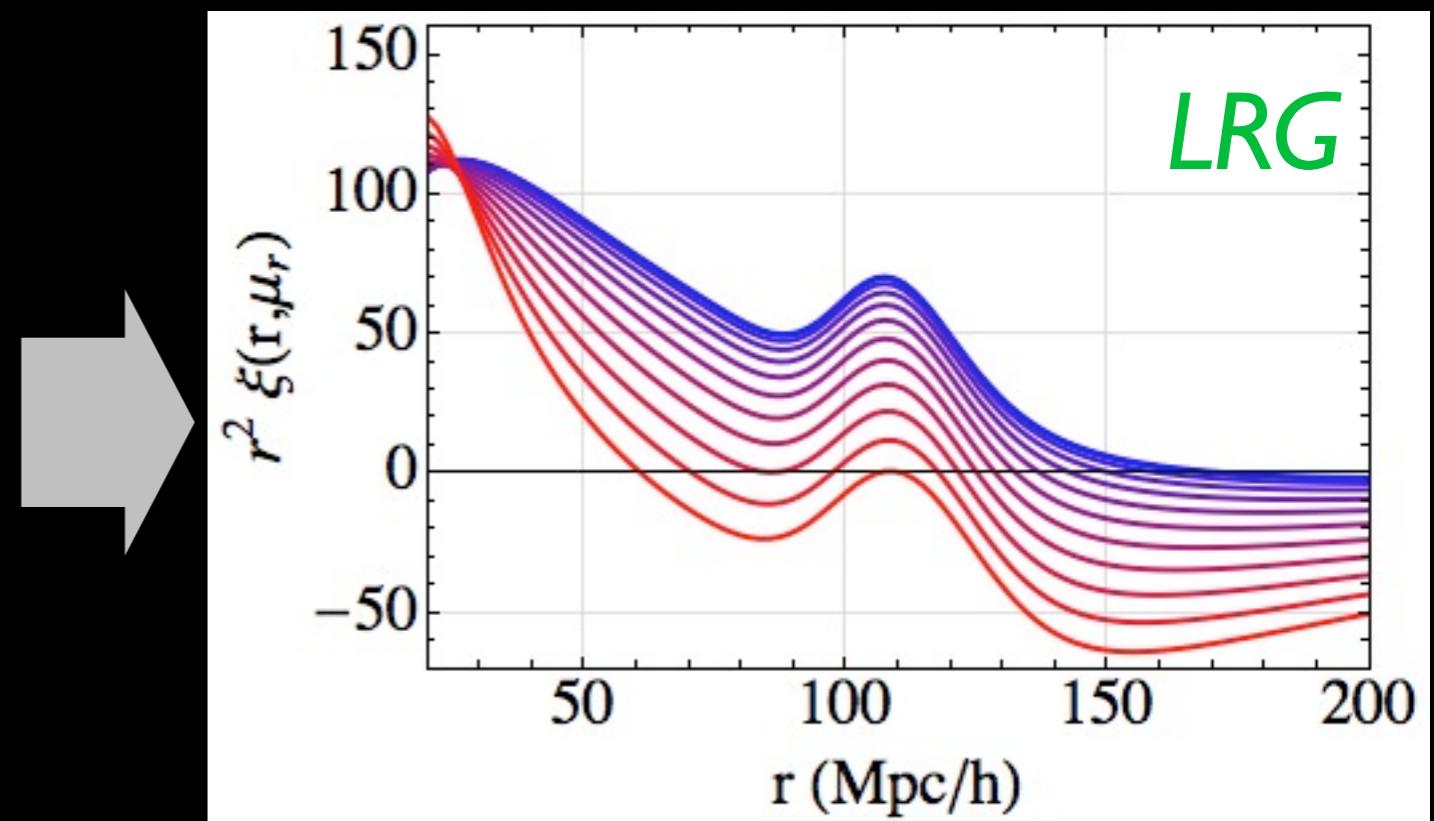
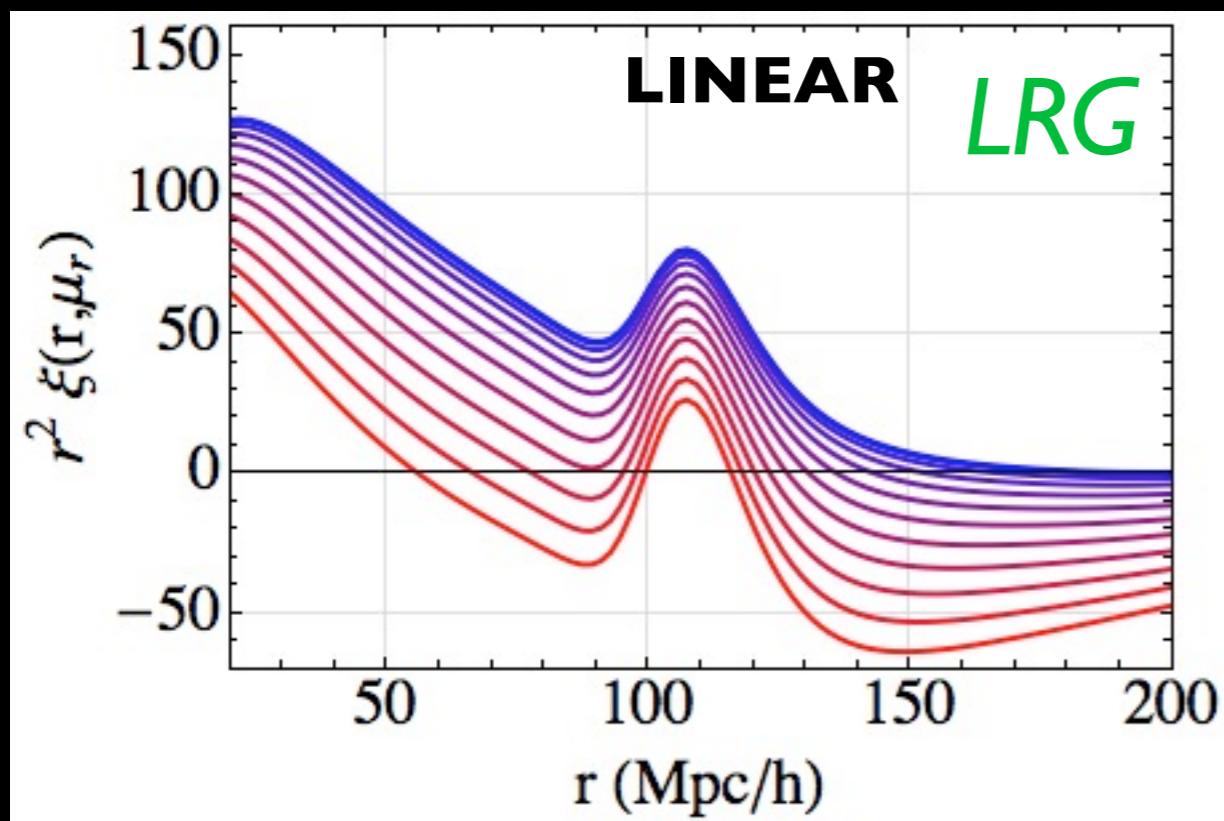
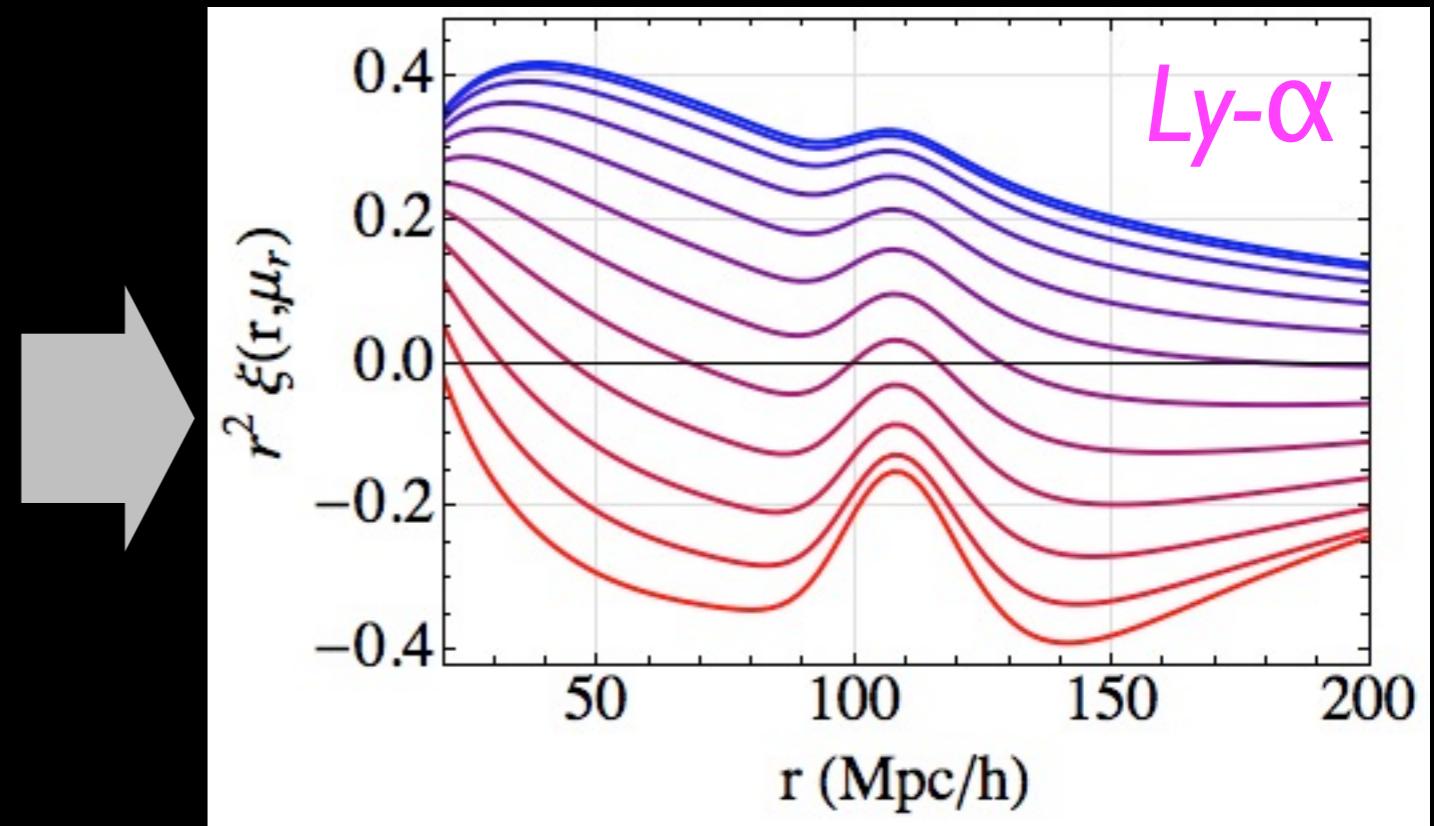
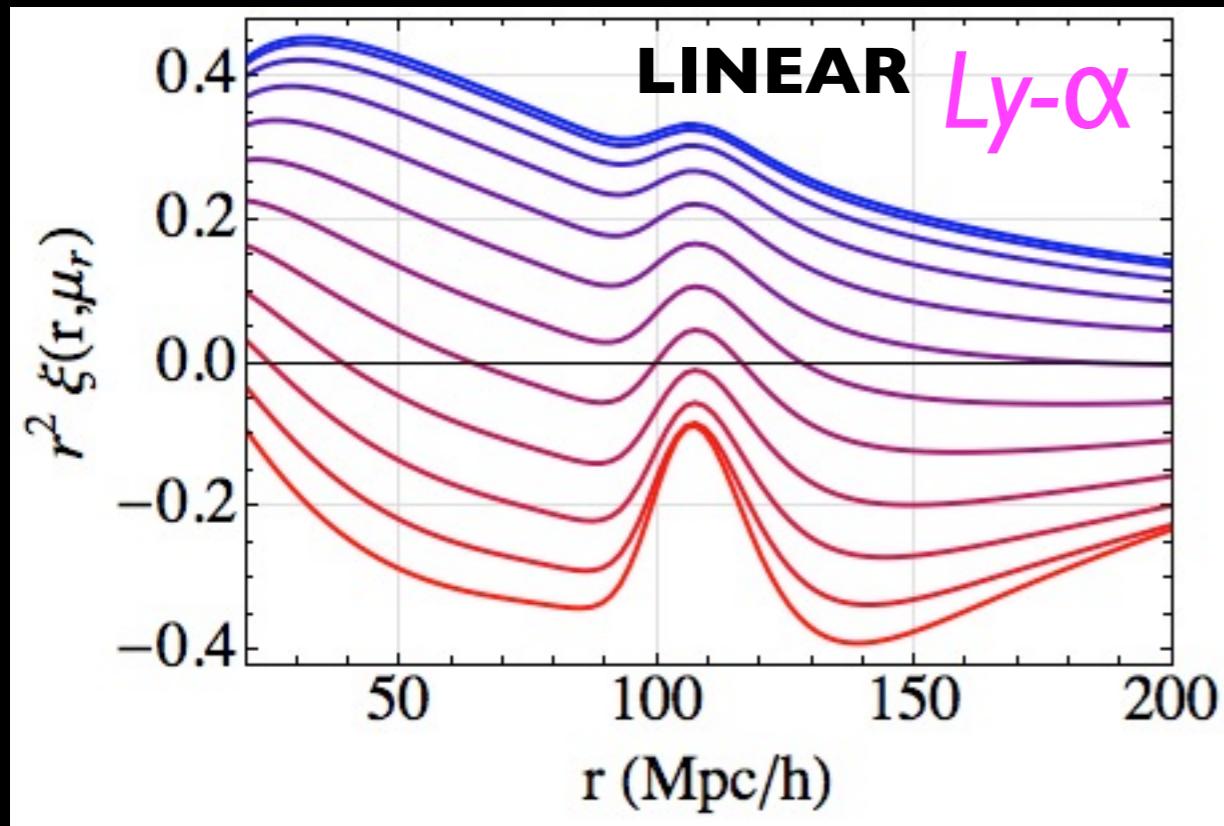


# Redshift Space Distortions

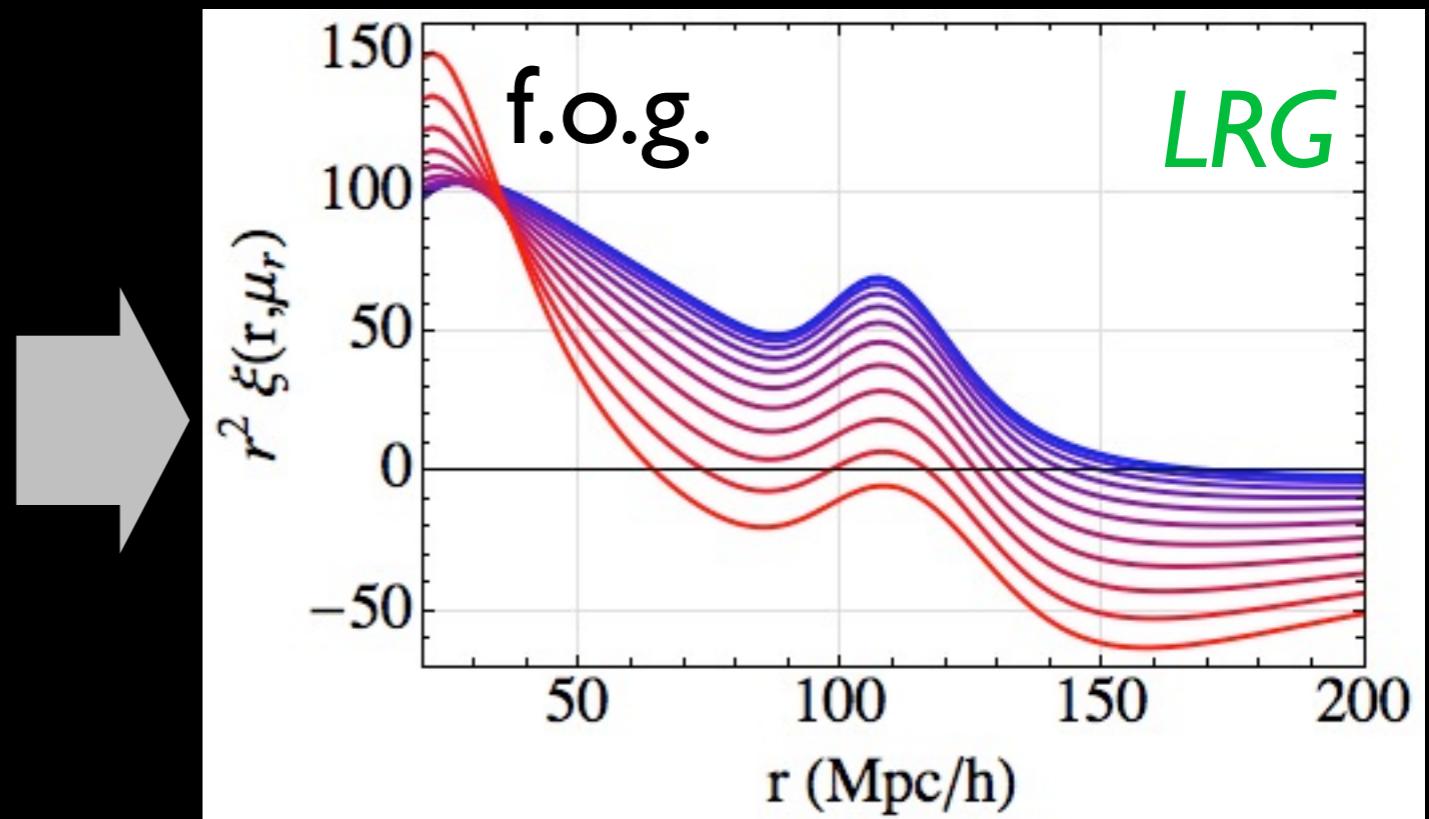
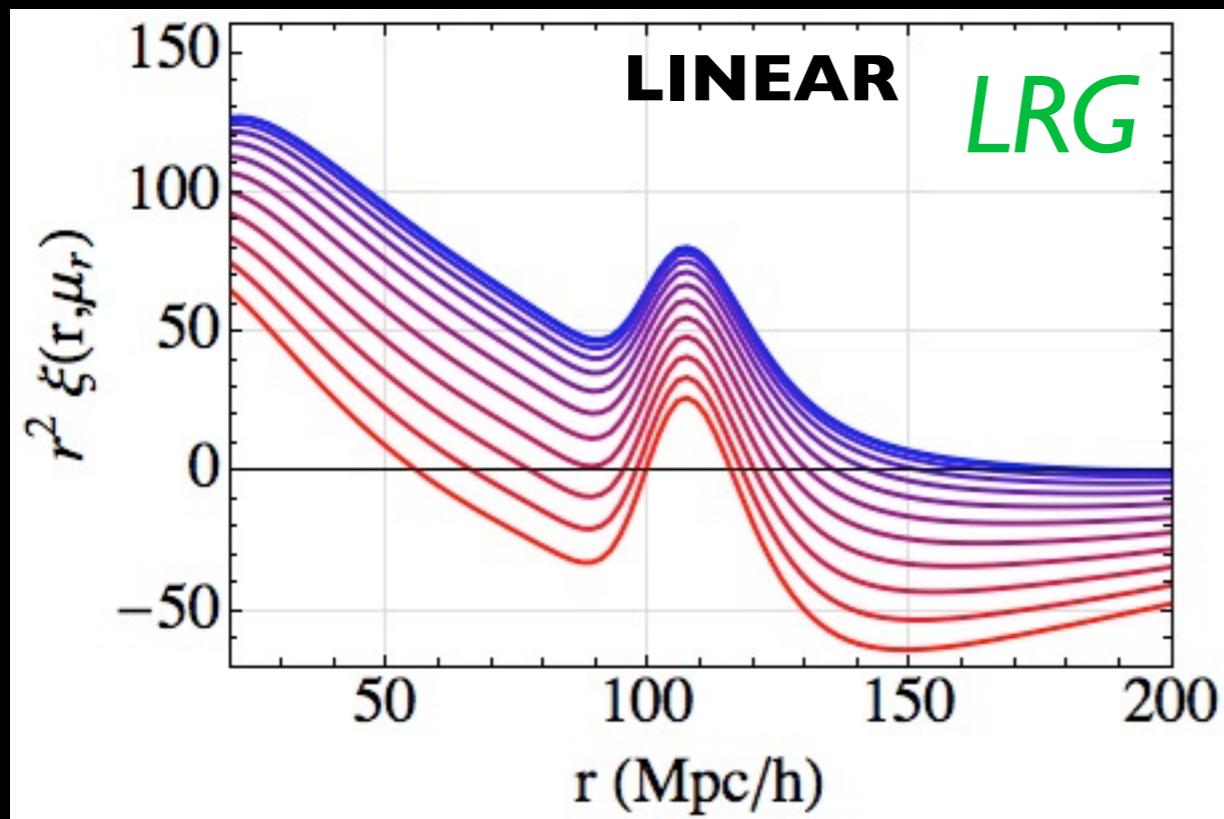
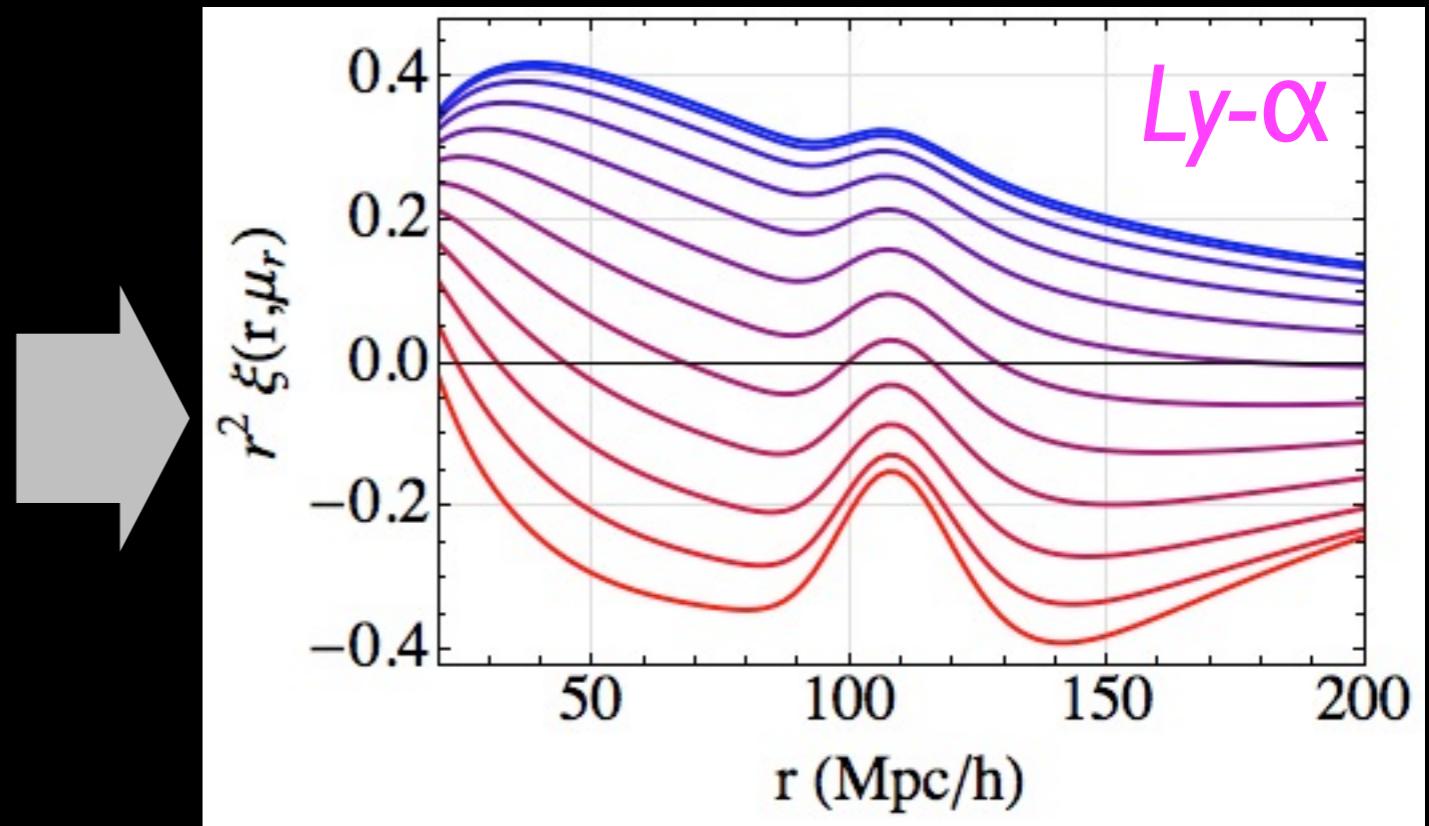
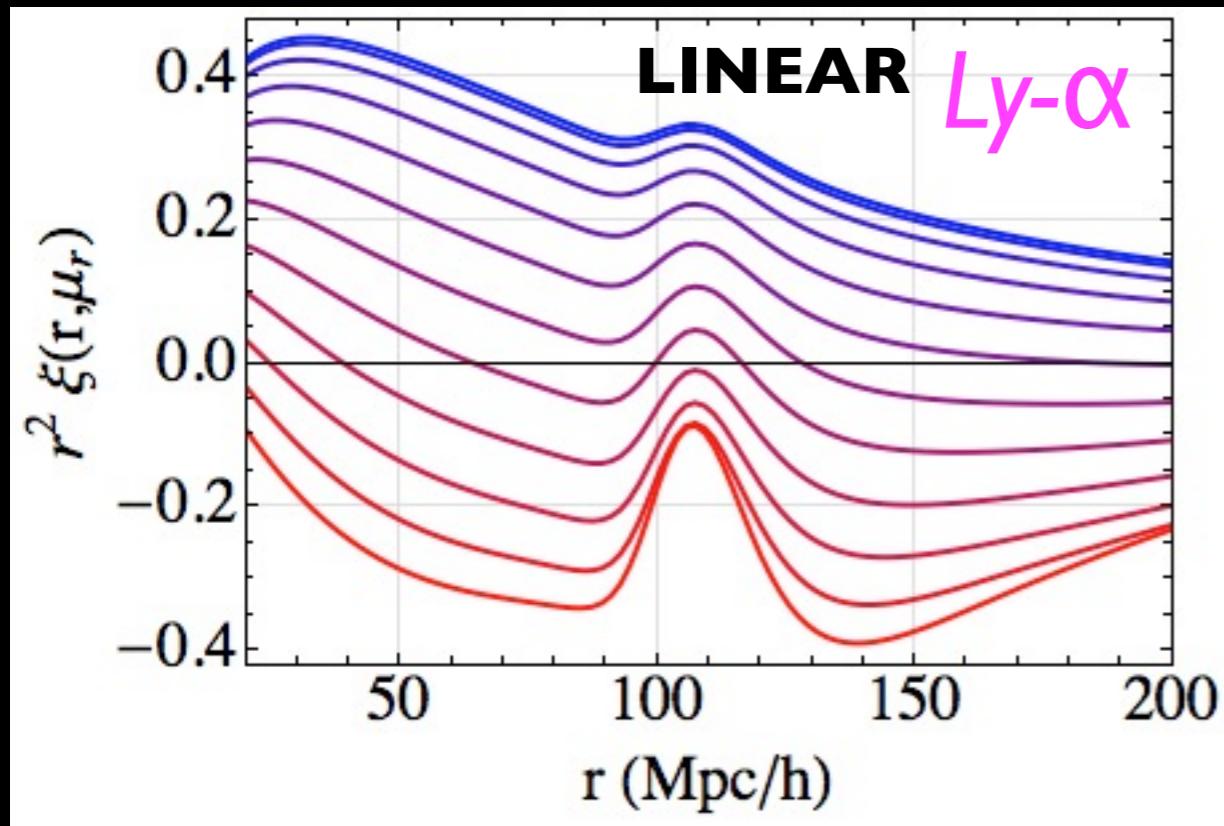


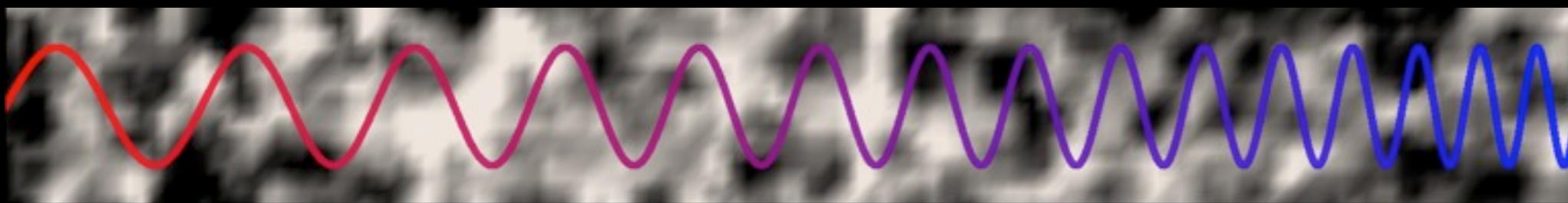
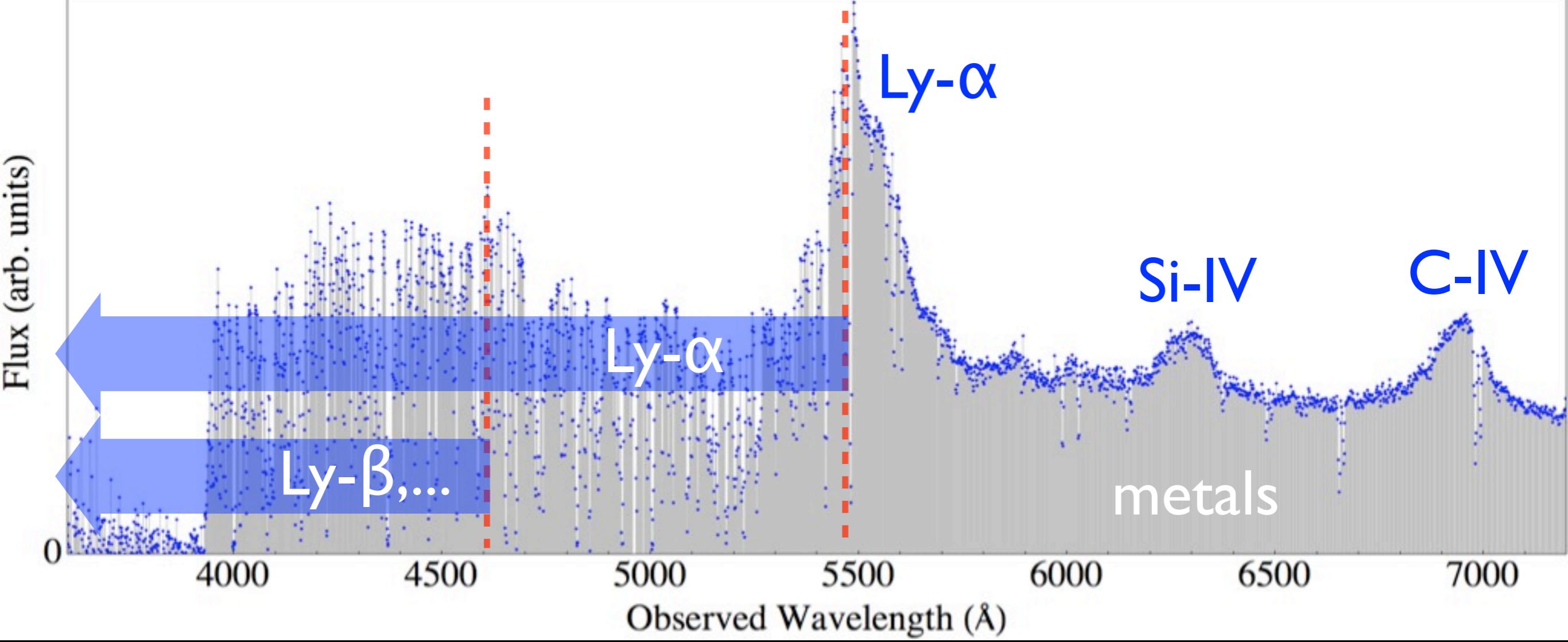


# Nonlinear Effects

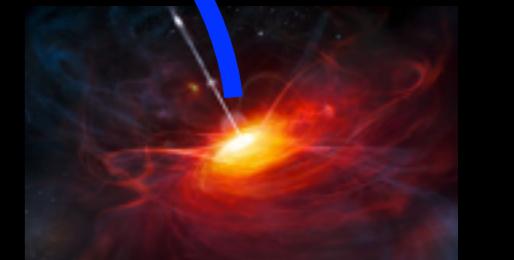


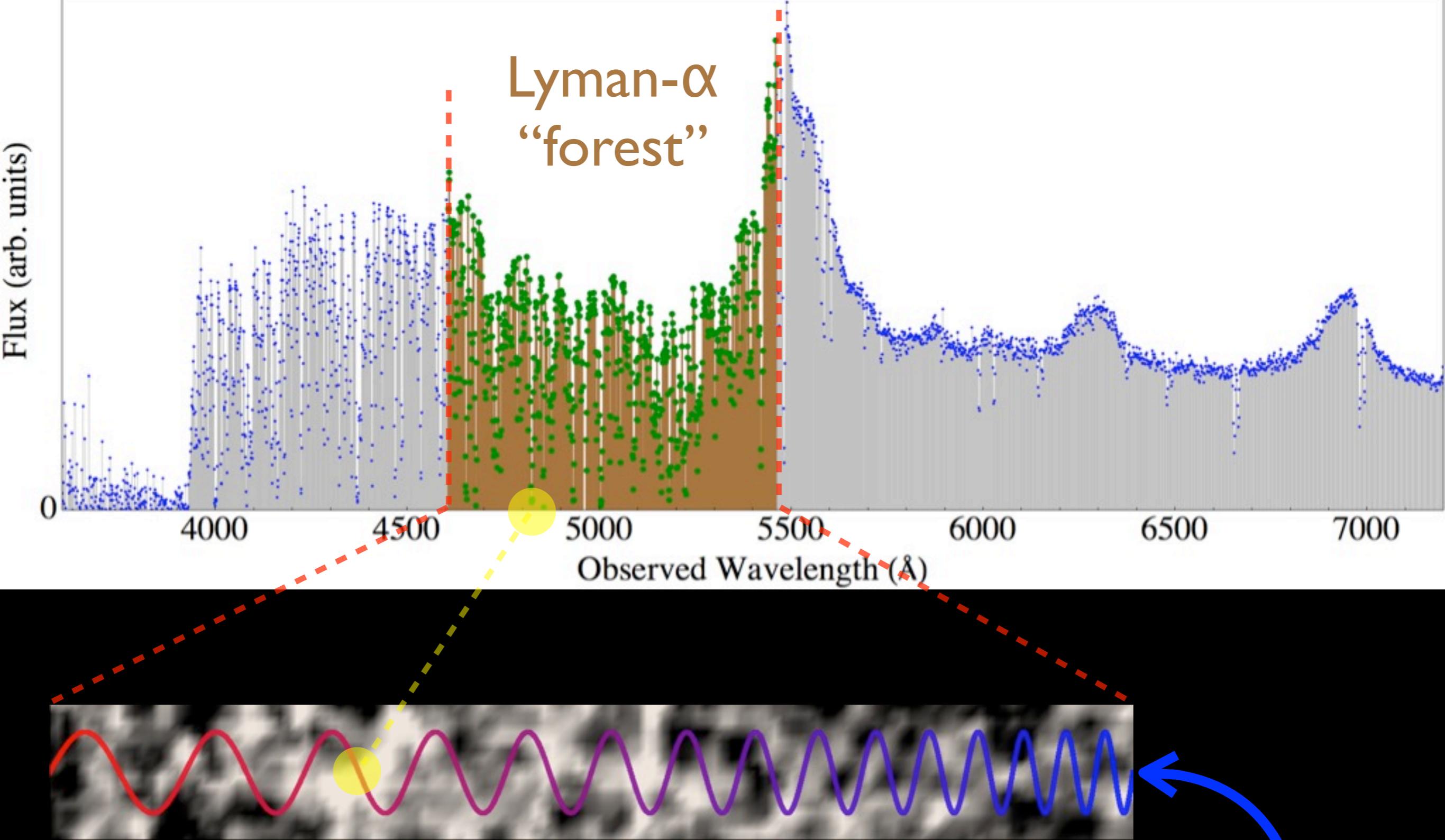
# Nonlinear Effects



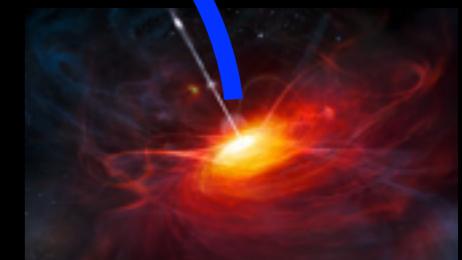


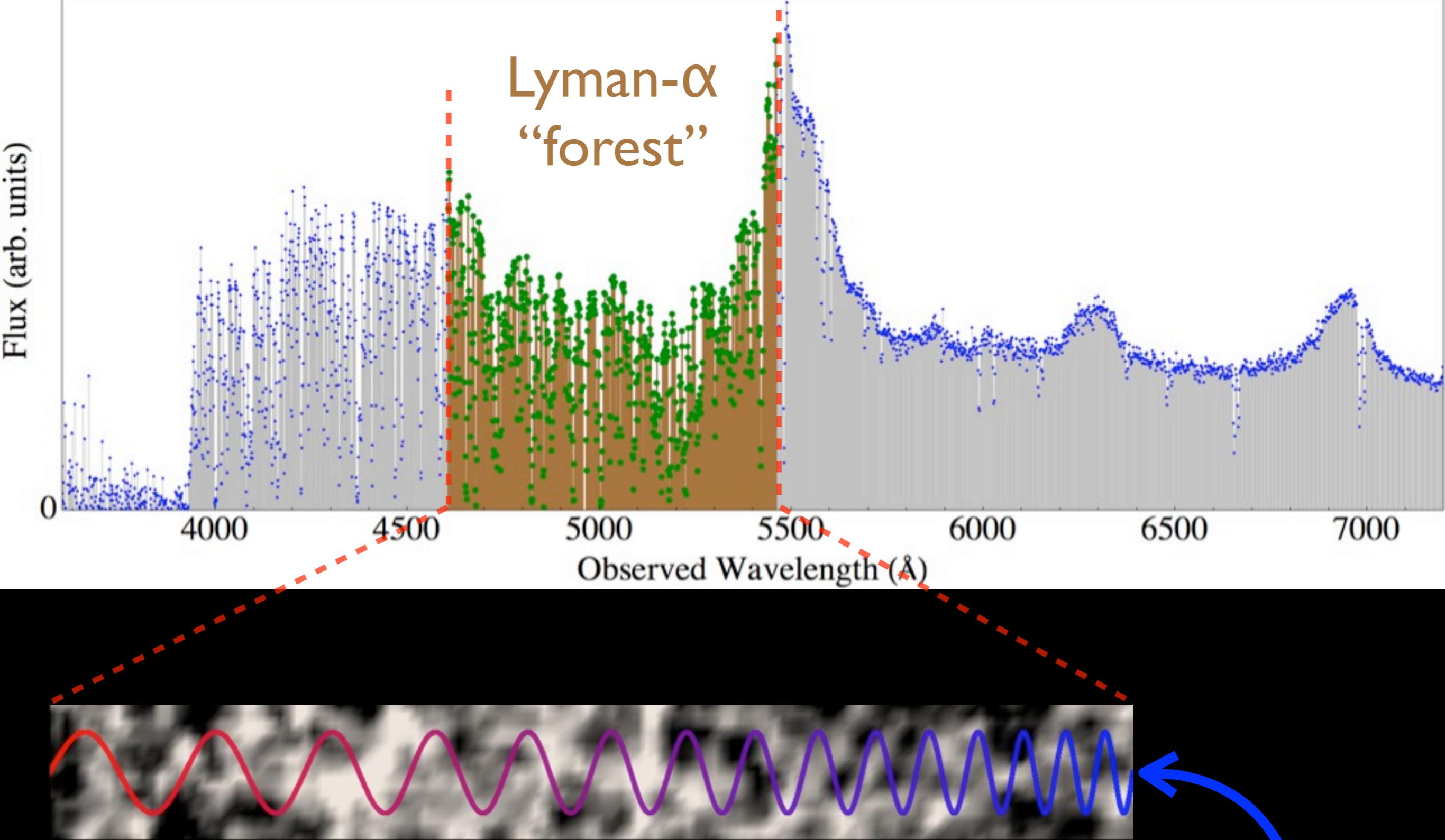
quasar photons travel through the  
Intergalactic Medium (IGM)  
which contains  $\sim 95\%$  of Universe's baryons



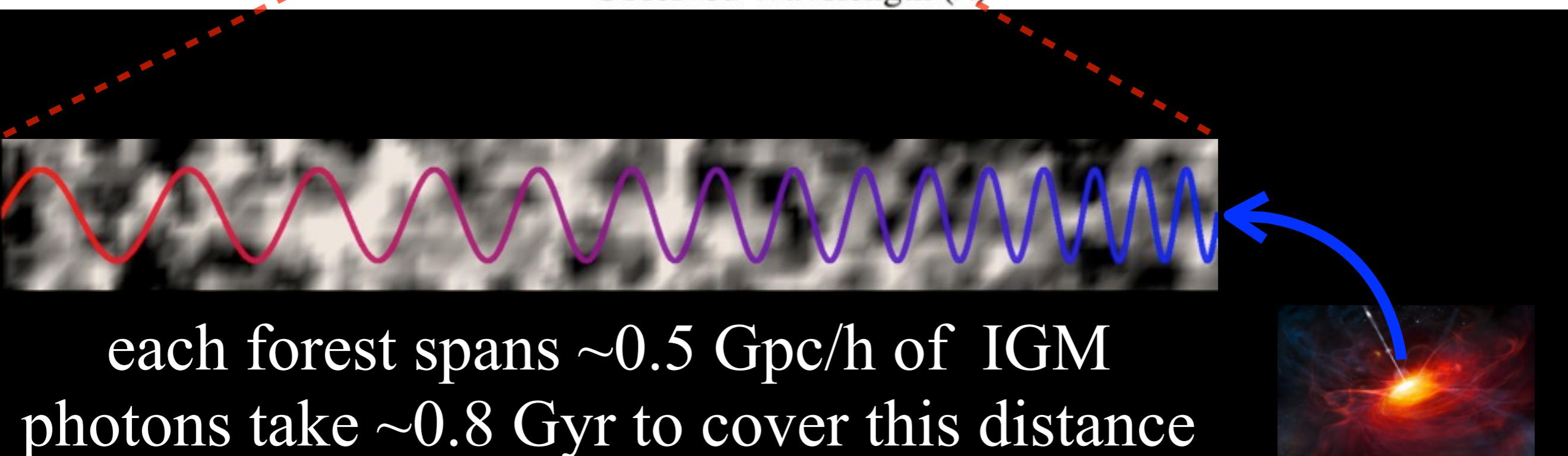


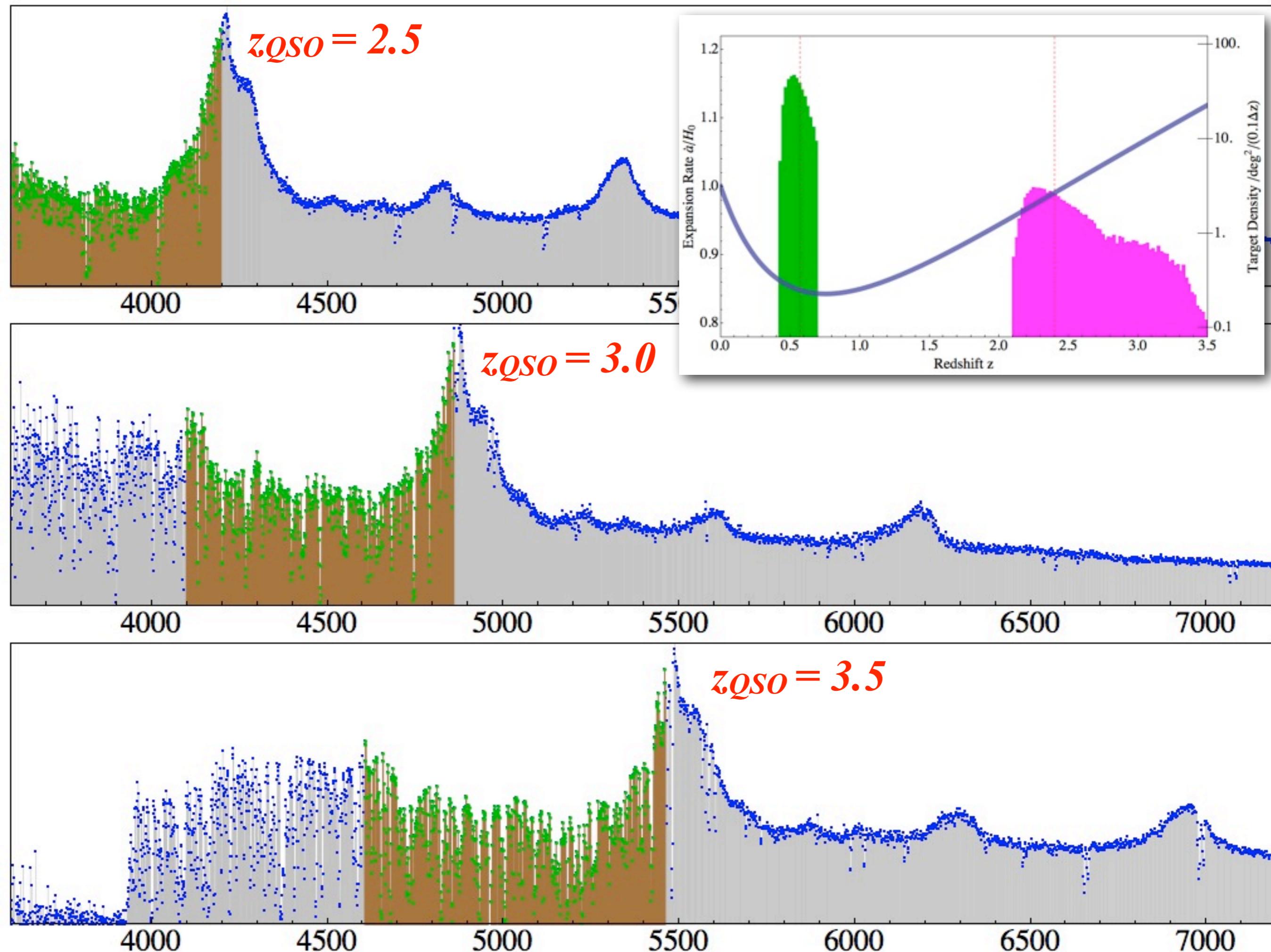
Absorption in the Lyman- $\alpha$  forest  
at  $\lambda_{\text{obs}}$  measures H-I density at  $1+z = \lambda_{\text{obs}}/\lambda_{\alpha}$

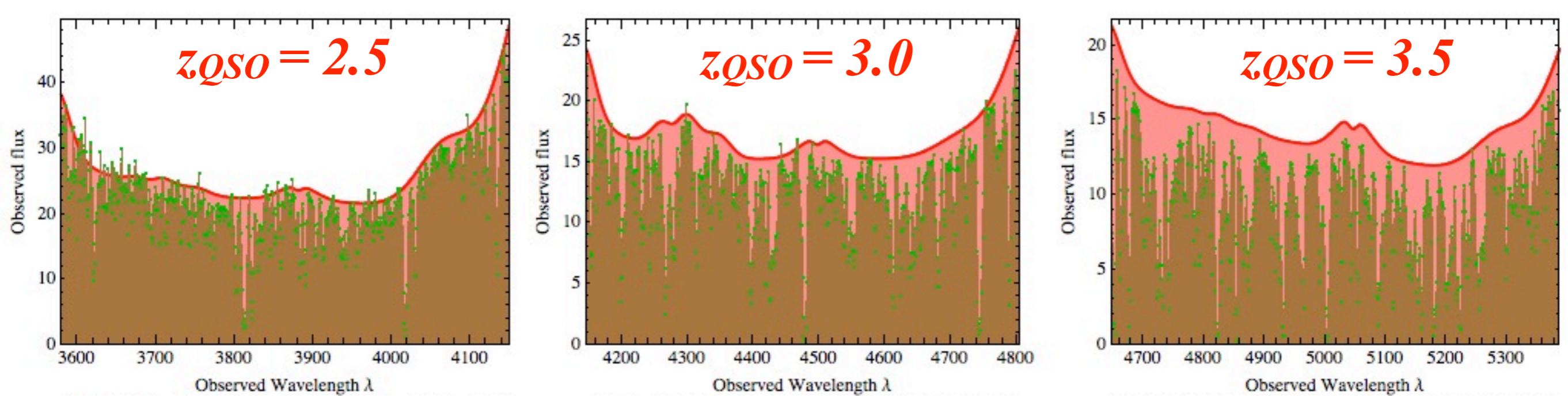




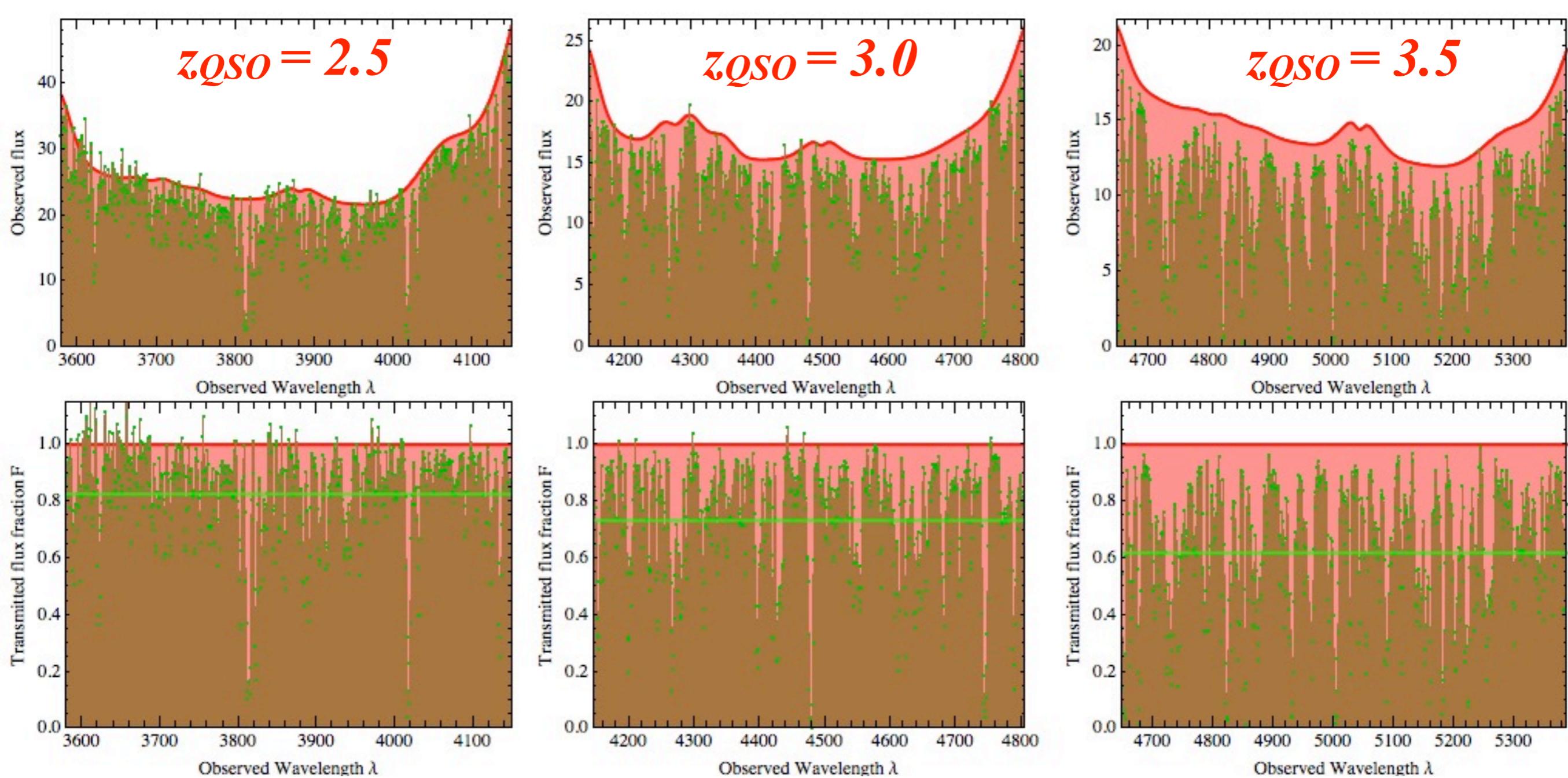
each forest spans  $\sim 0.5 \text{ Gpc/h}$  of IGM  
photons take  $\sim 0.8 \text{ Gyr}$  to cover this distance  
BOSS samples  $1\text{\AA} \sim 1 \text{ Mpc}$  per pixel



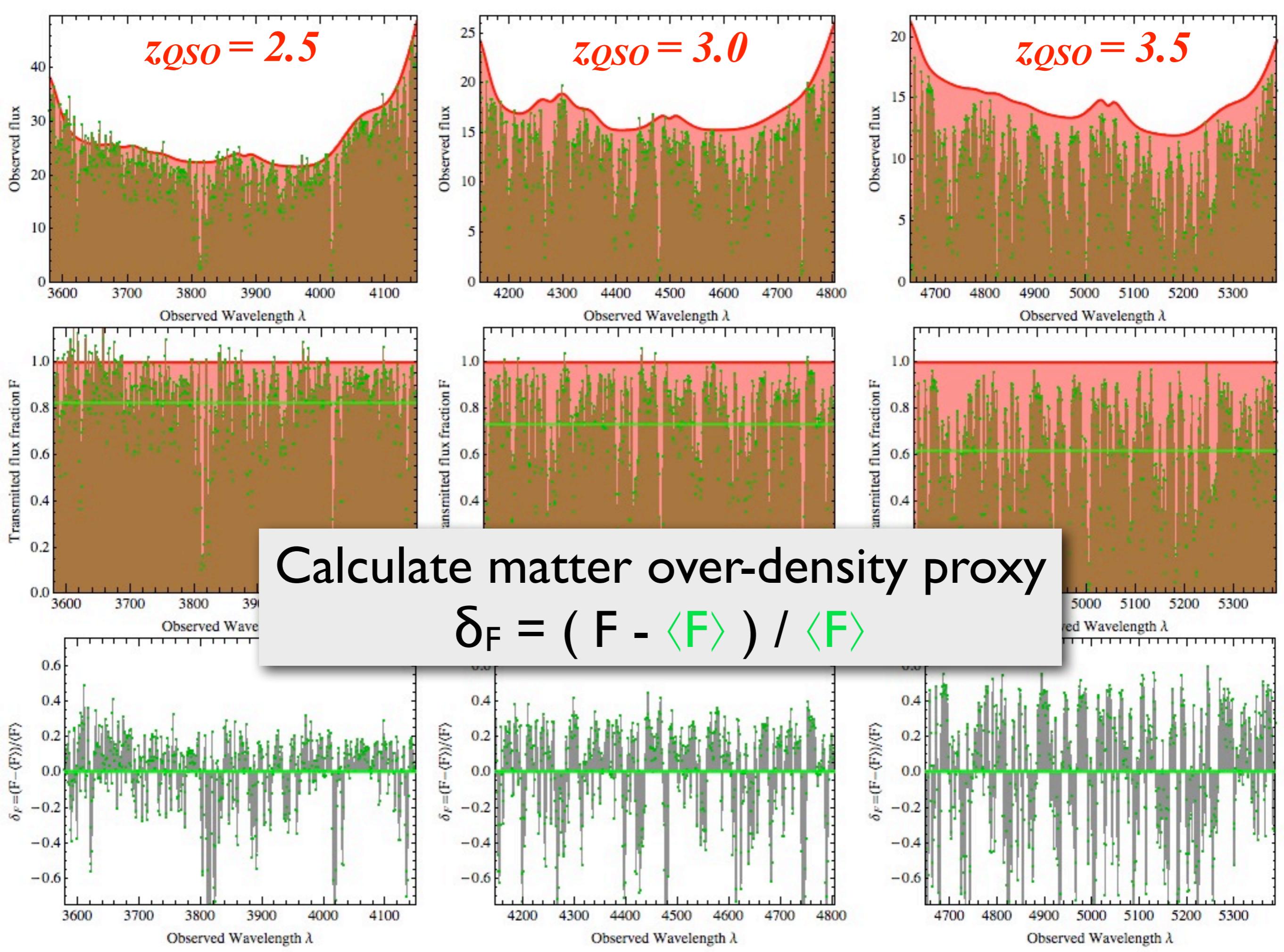


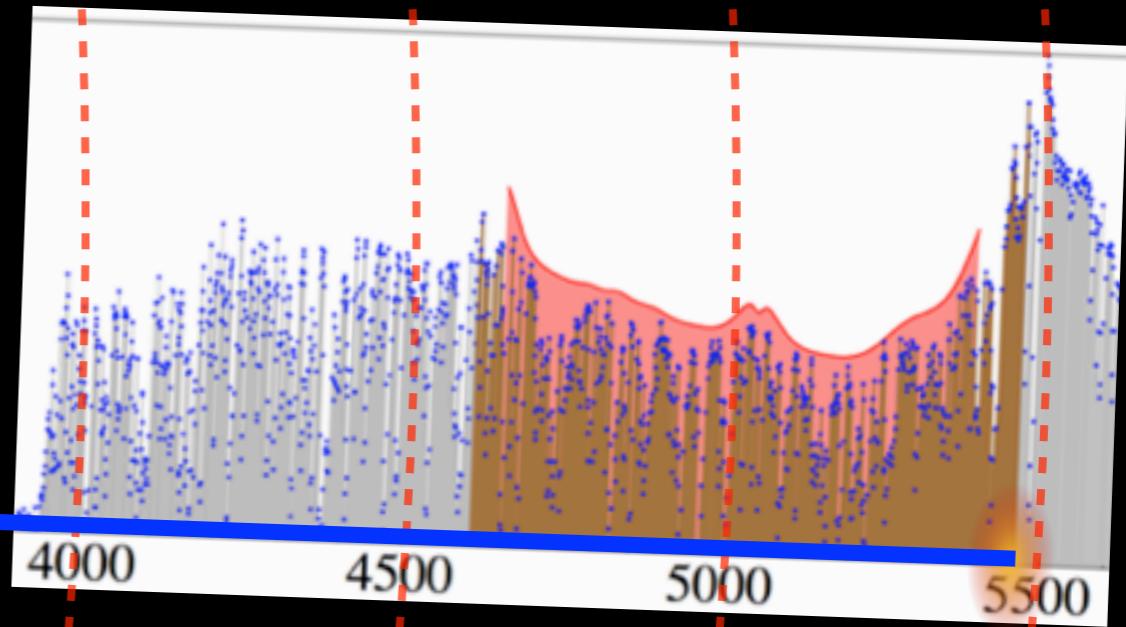
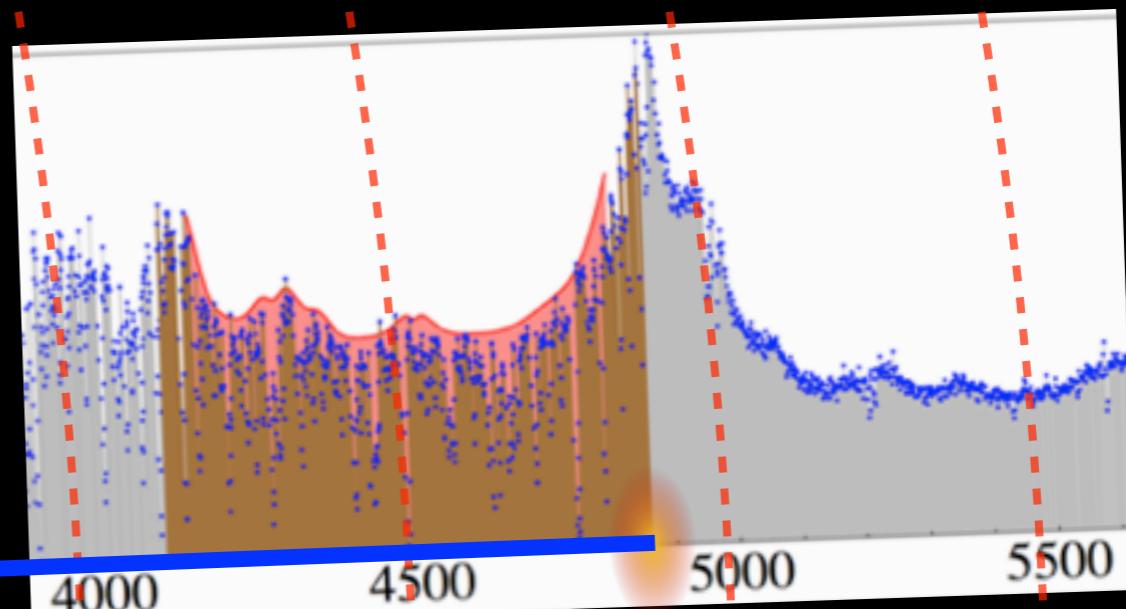


Estimate what **continuum flux** would be  
without any Ly-a absorption

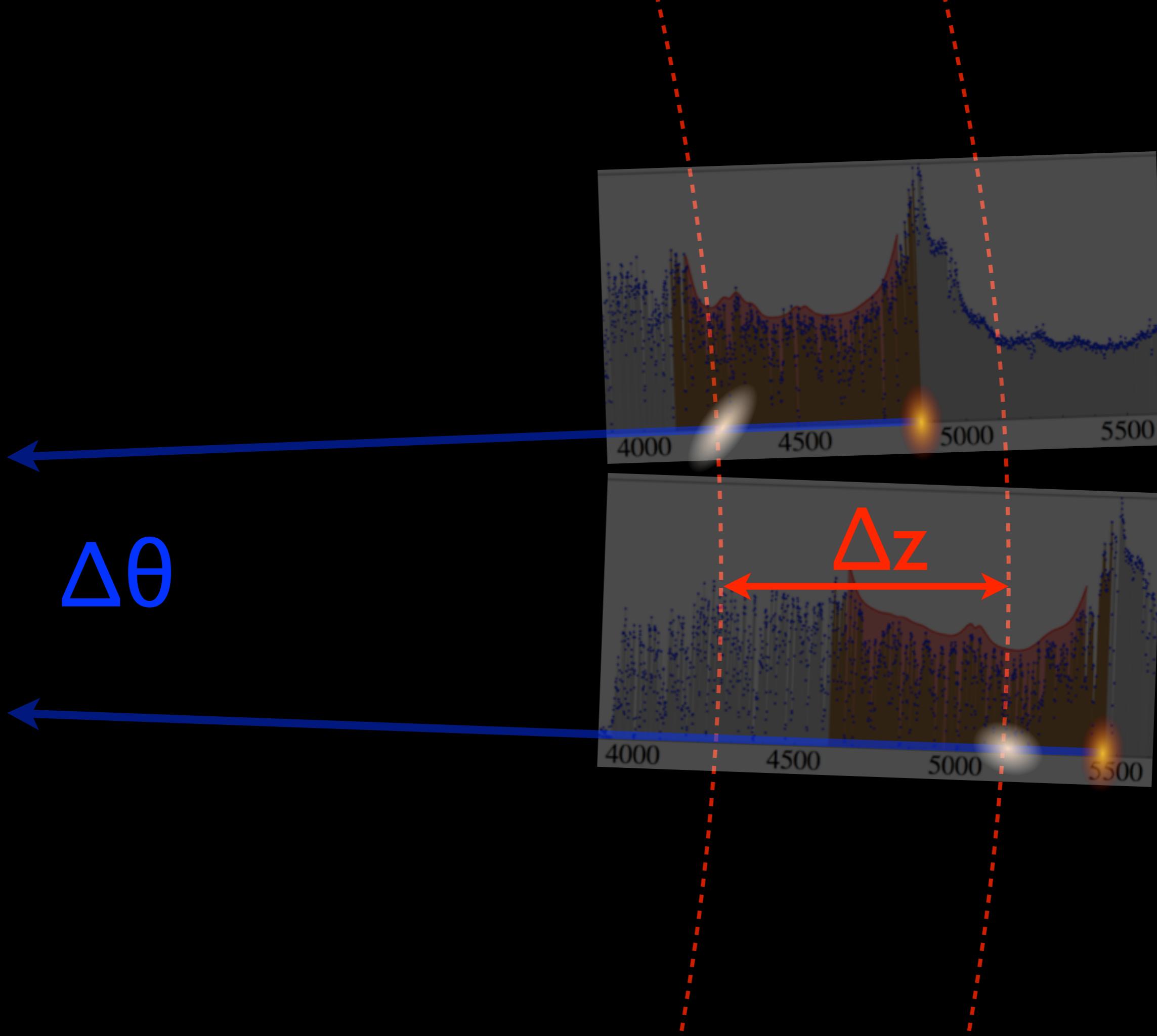


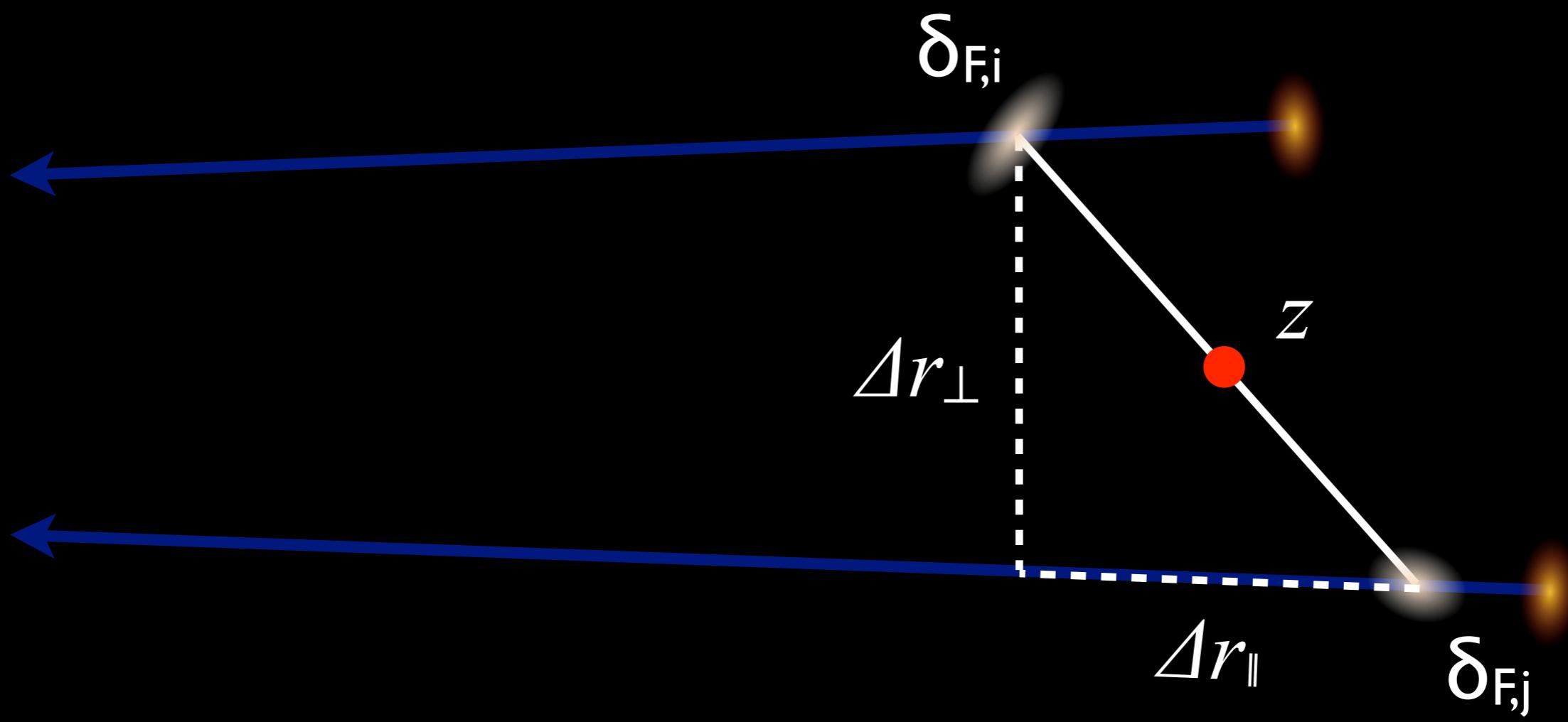
**Calculate transmitted flux fraction**  
 $F = \text{observed flux} / \text{continuum flux}$



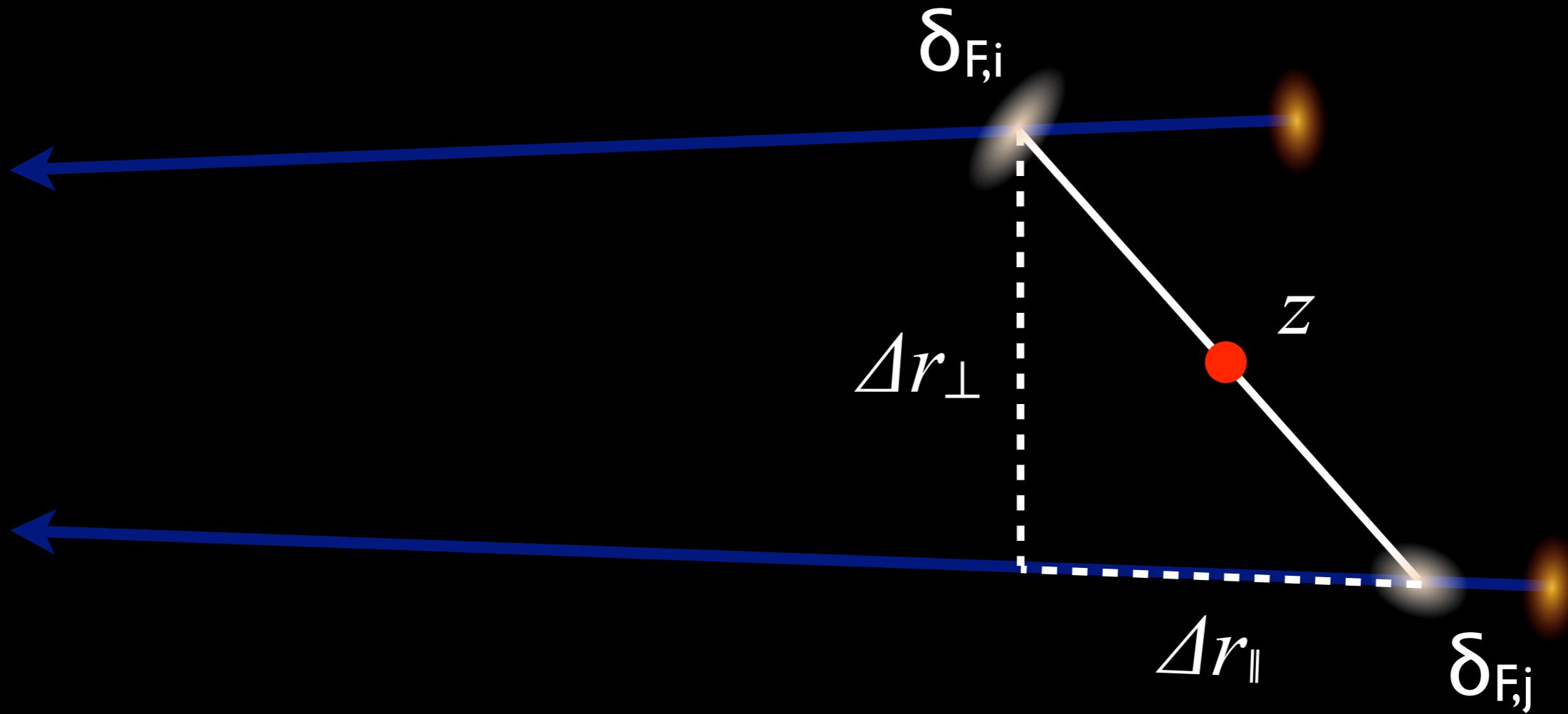


observed  $\lambda \sim$  absorption  $z$

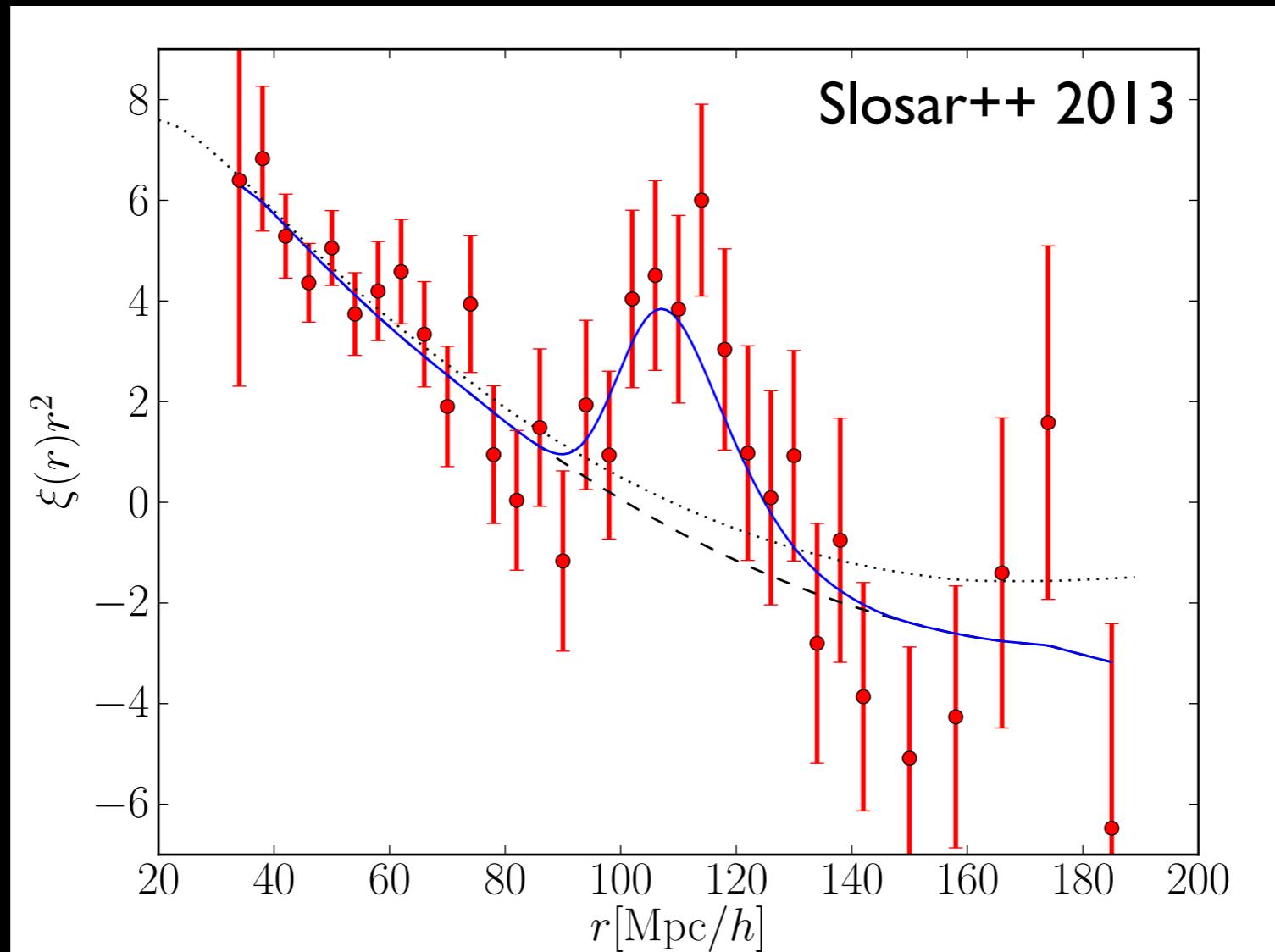




Fit 3D correlation function  $\xi_F(\Delta r_\perp, \Delta r_\parallel, z)$   
of  $\delta_F$  field to measure  $D_A(z)/r_s$  and  $c/(r_s H(z))$   
assuming isotropic BAO peak with size  $r_s$

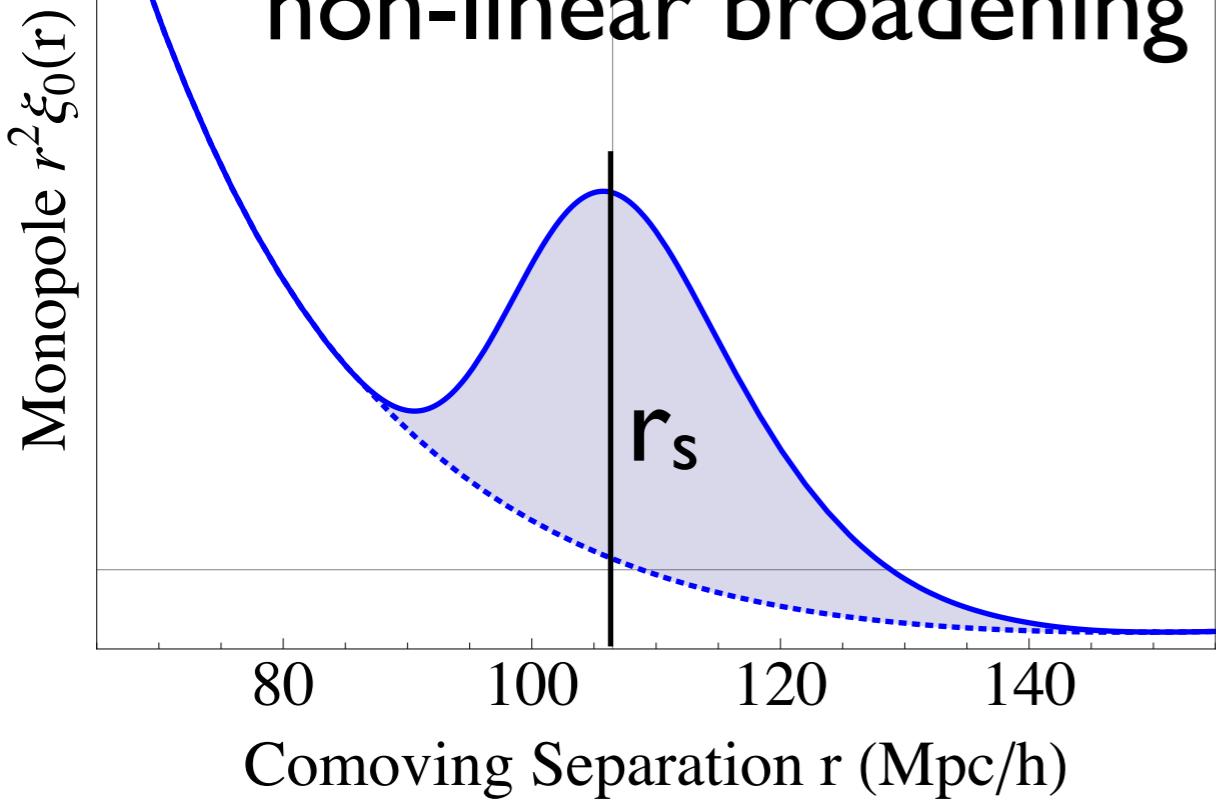


Fit 3D correlation function  $\xi_F(\Delta r_{\perp}, \Delta r_{\parallel}, z)$   
of  $\delta_F$  field to measure  $D_A(z)/r_s$  and  $c/(r_s H(z))$   
assuming isotropic BAO peak with size  $r_s$

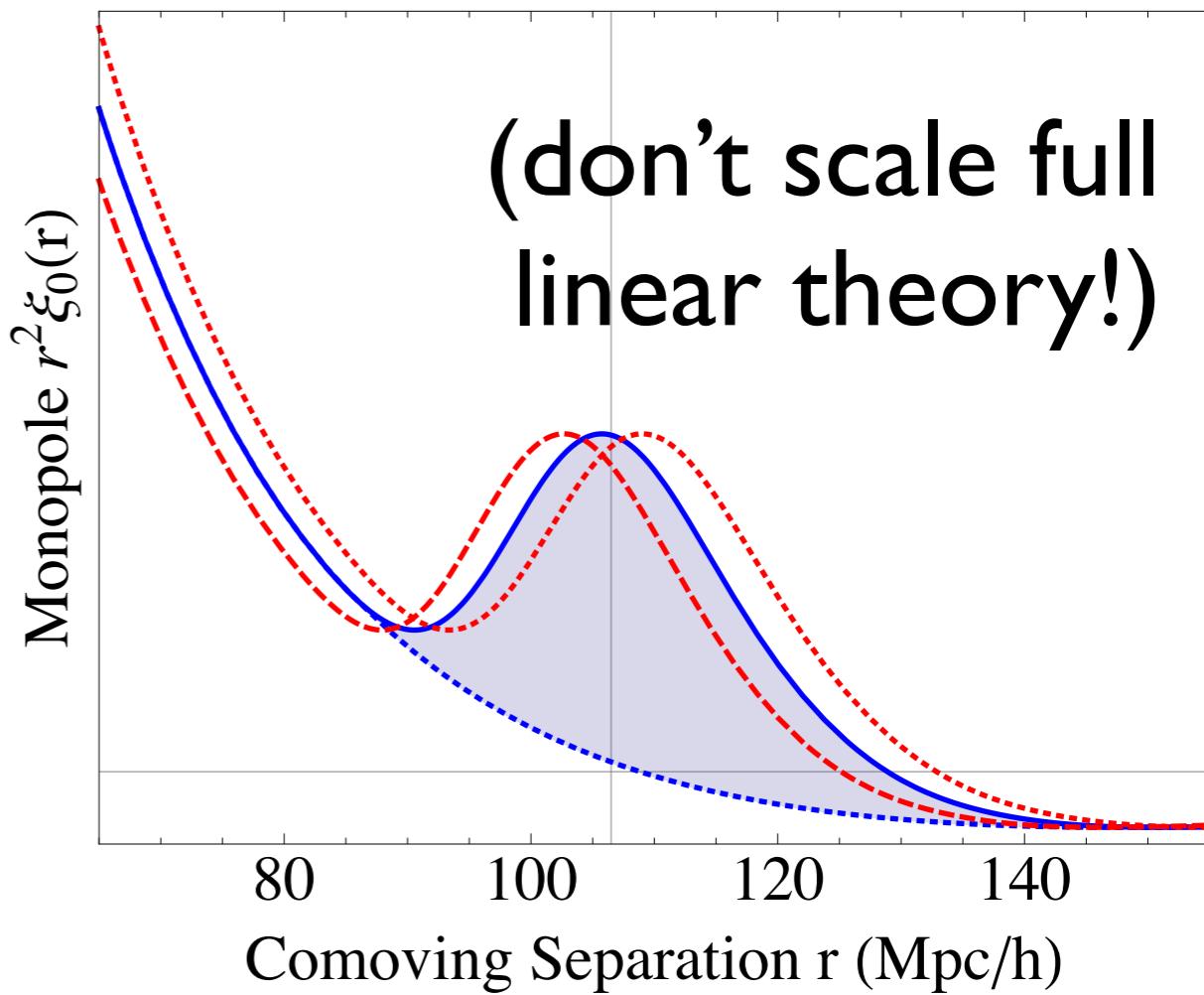
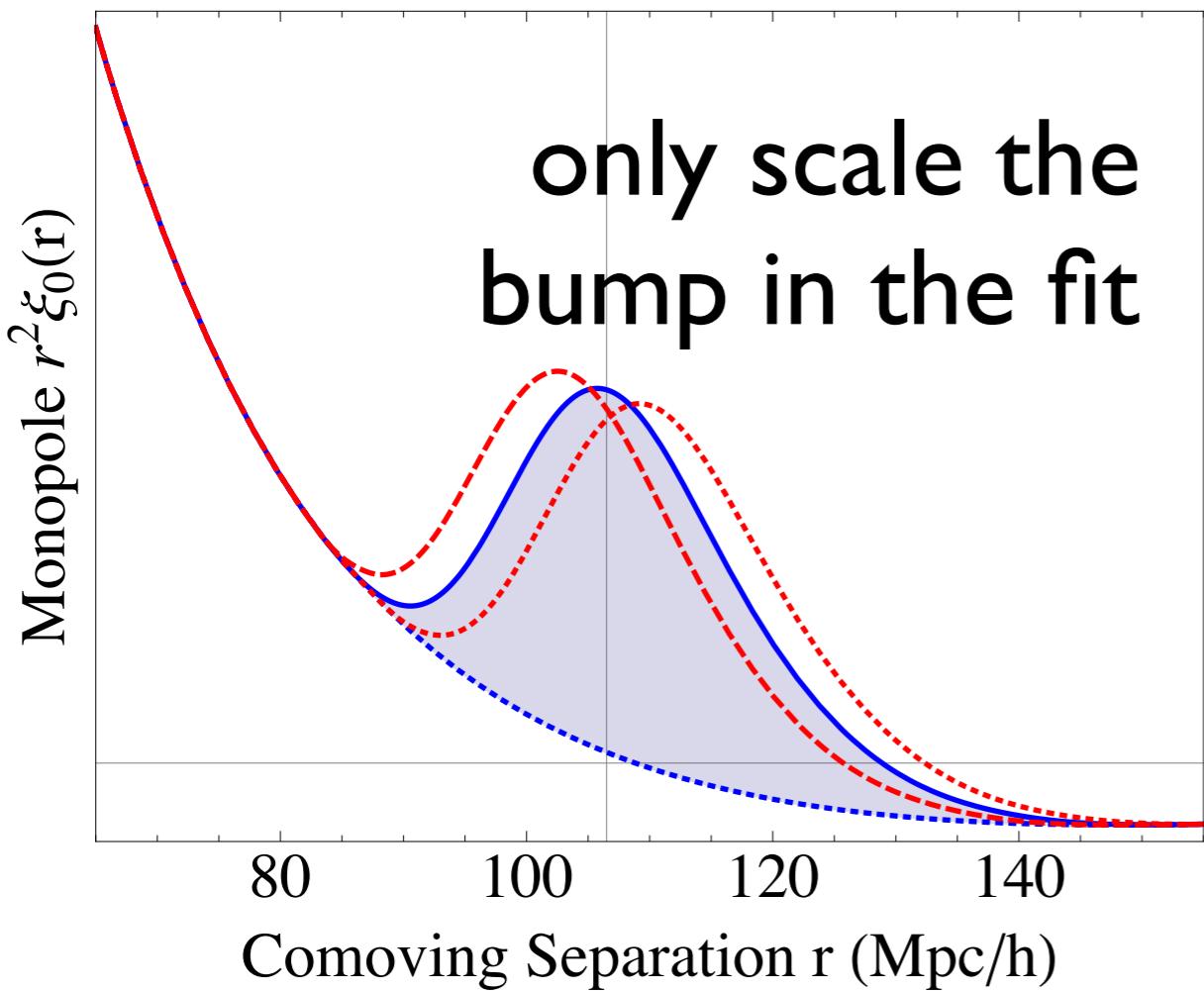
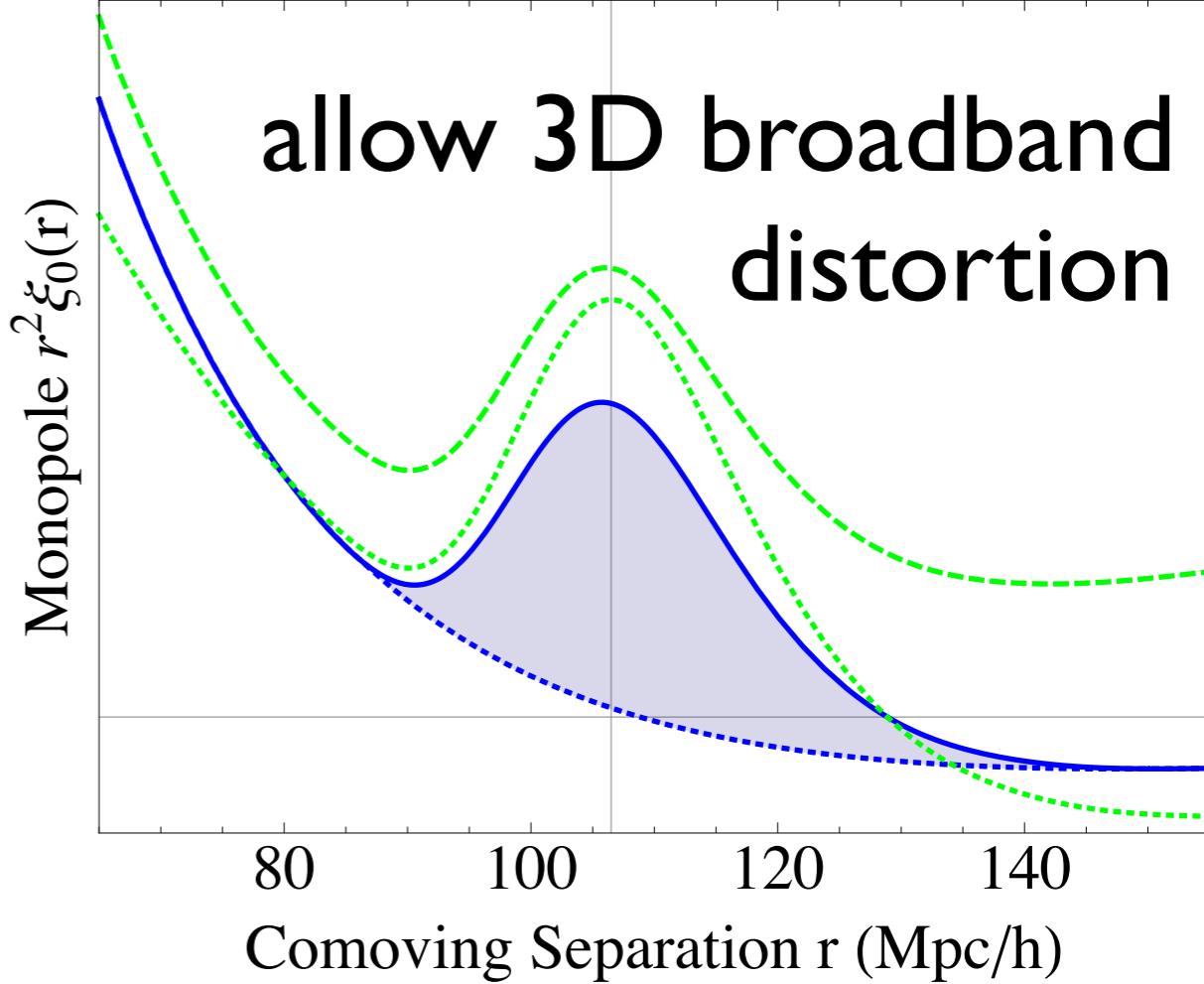


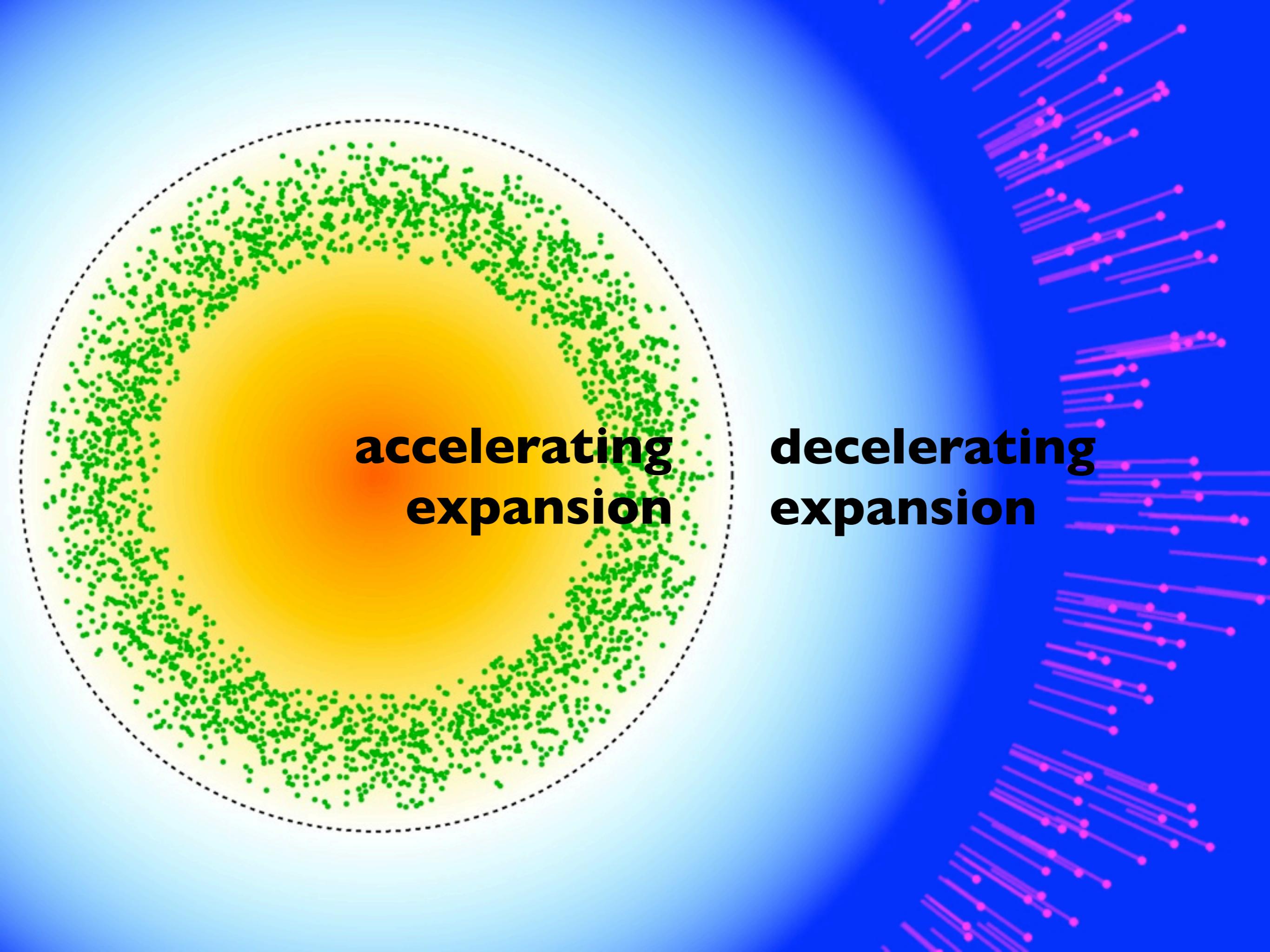
BOSS DR9 Ly $\alpha$  monopole

linear theory+RSD+  
non-linear broadening



allow 3D broadband  
distortion

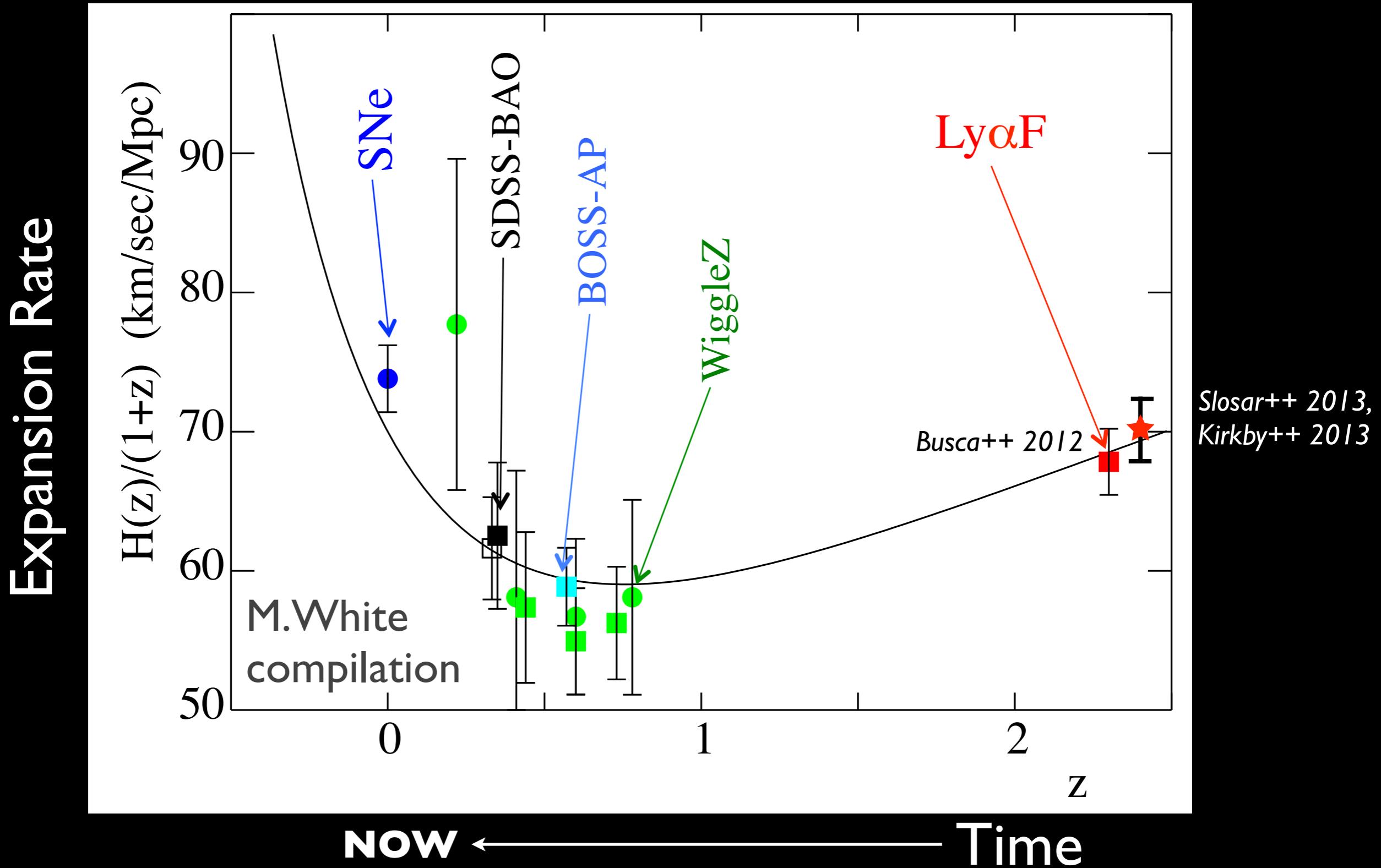


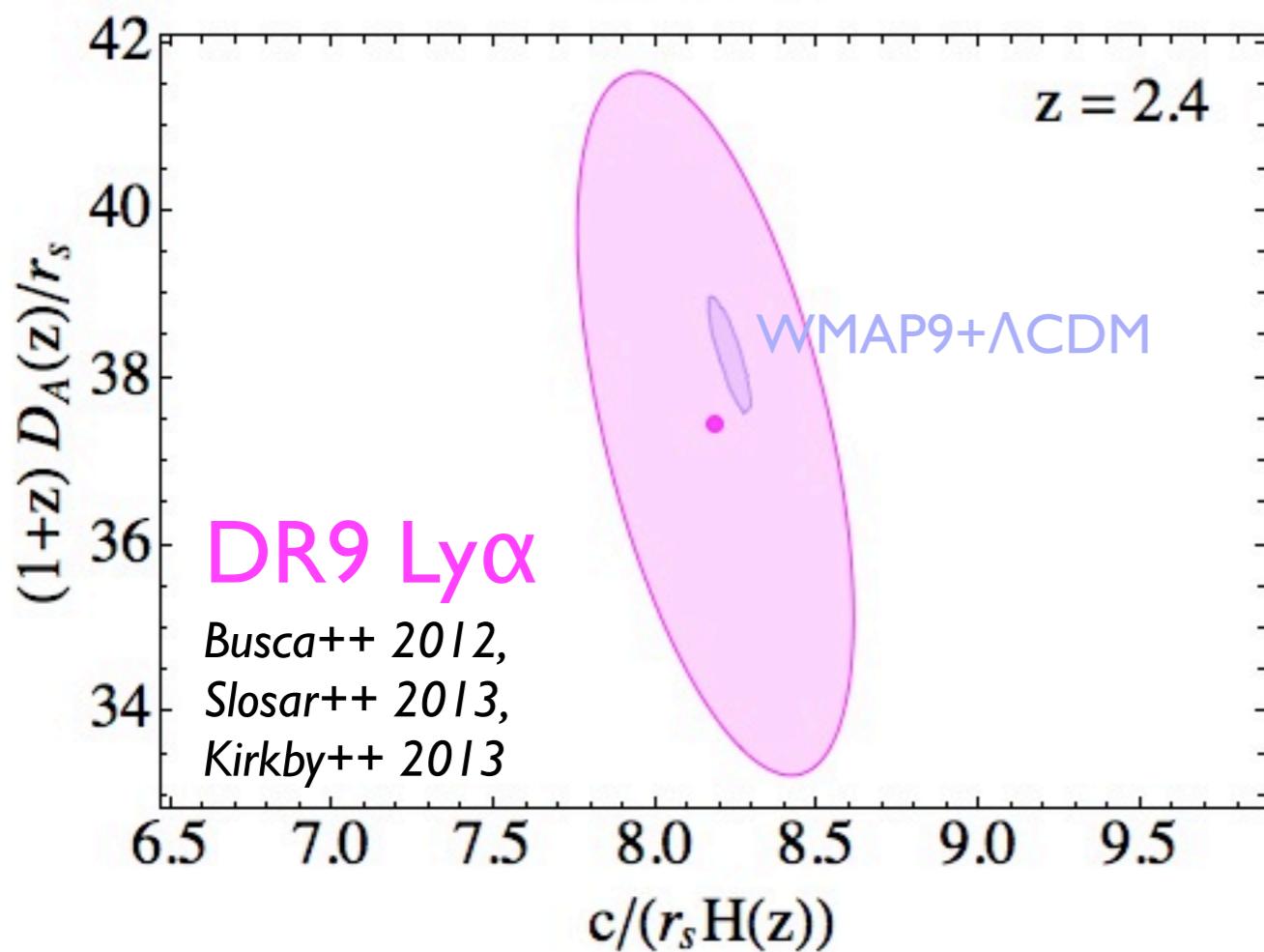
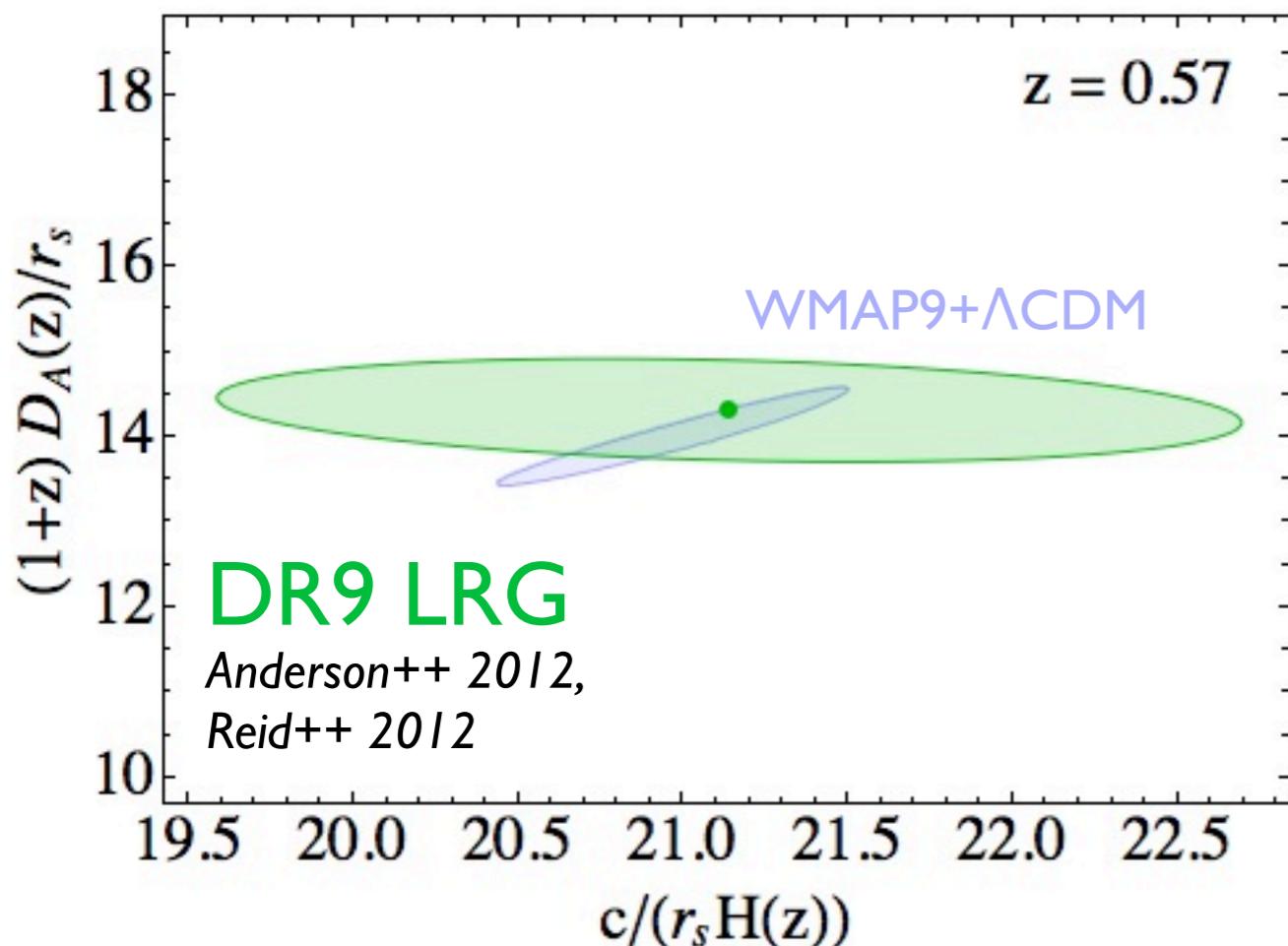


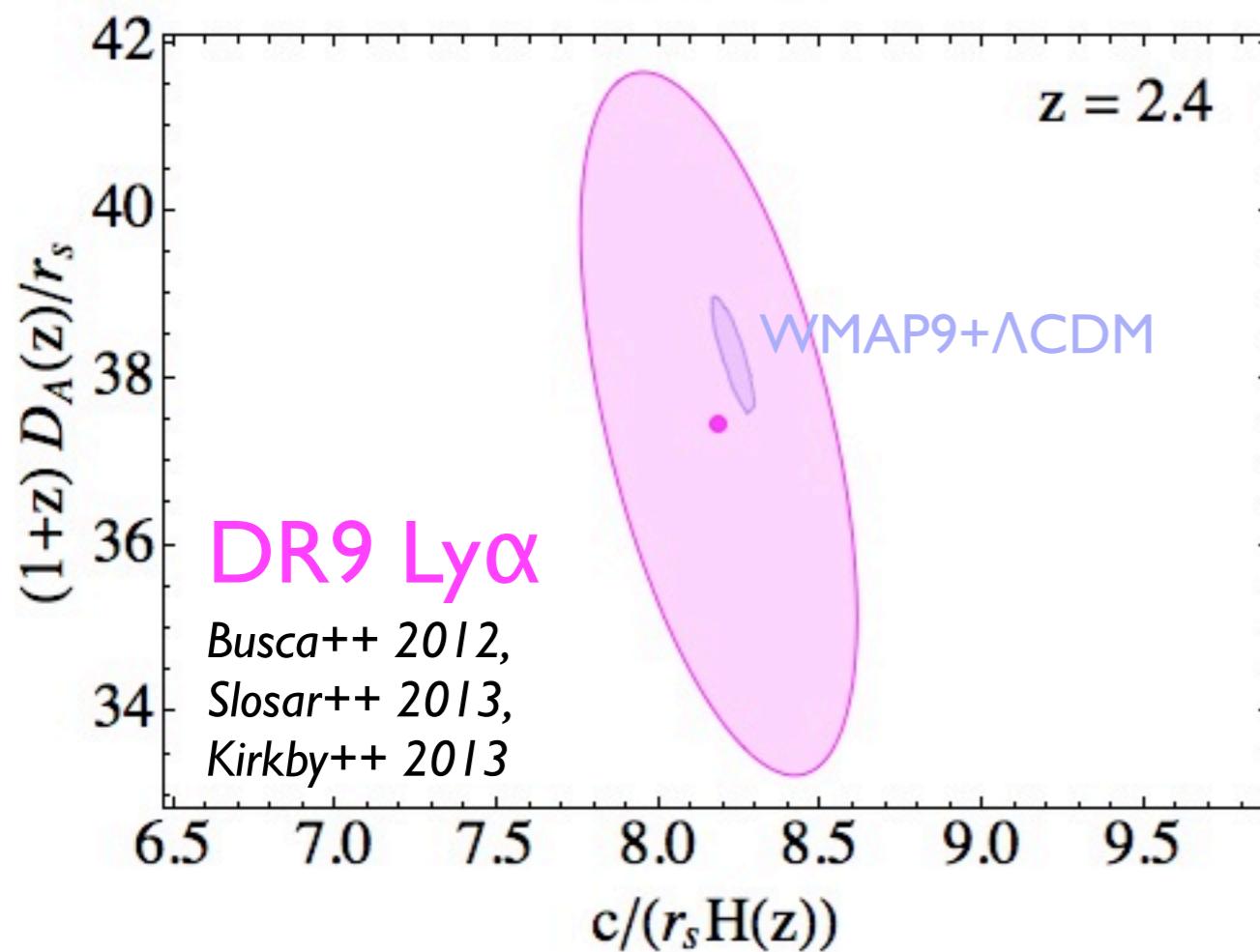
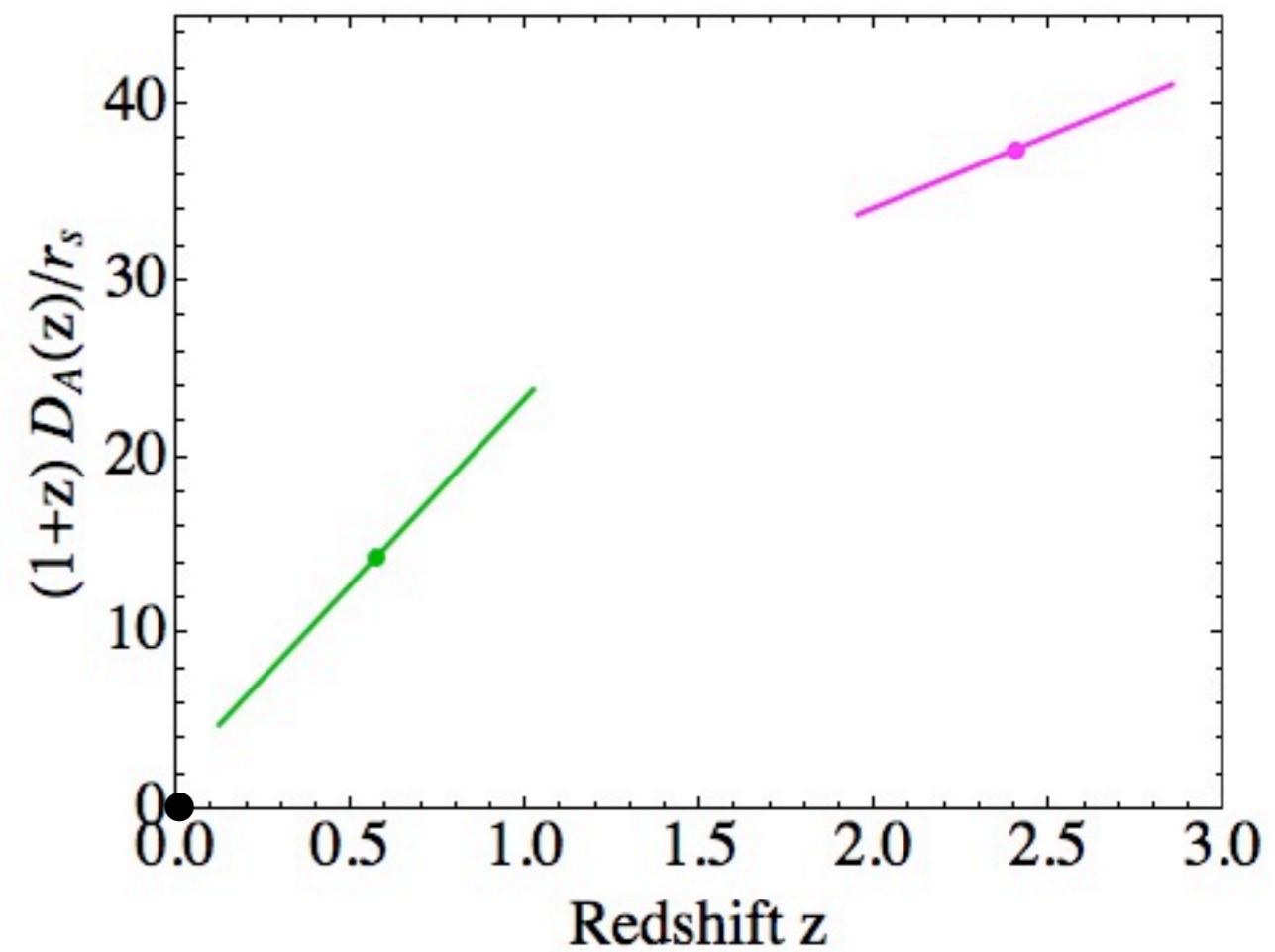
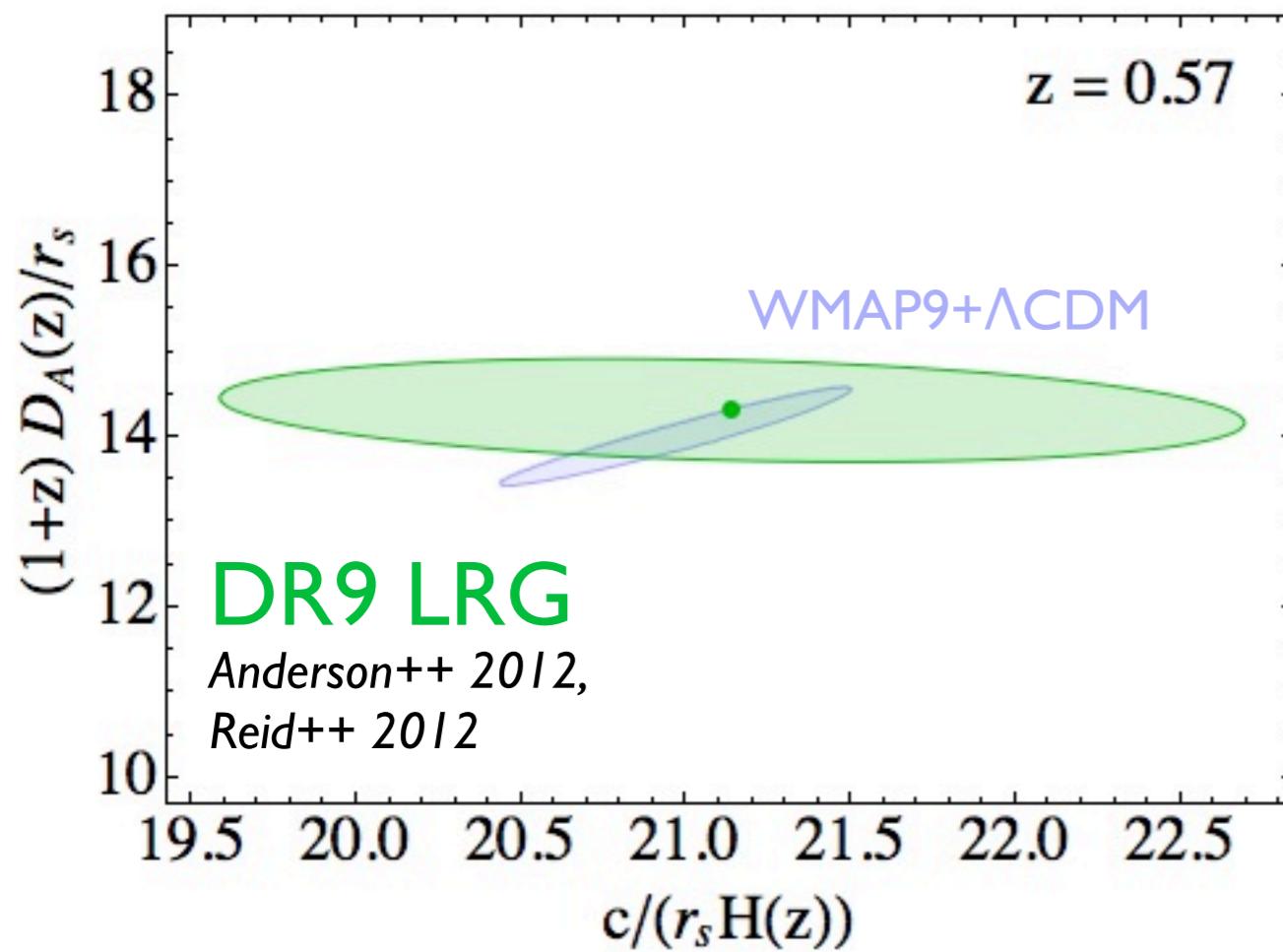
**accelerating  
expansion**

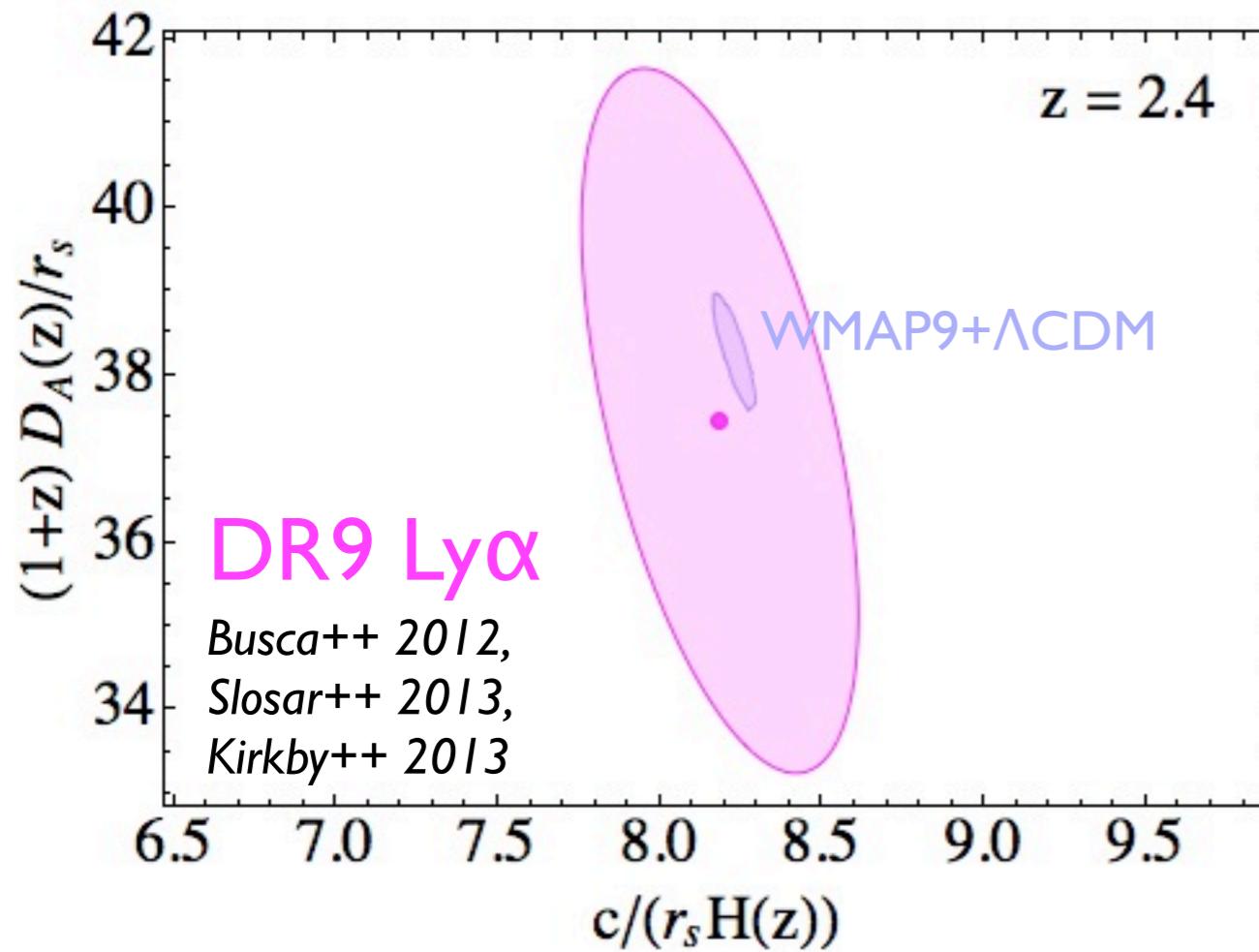
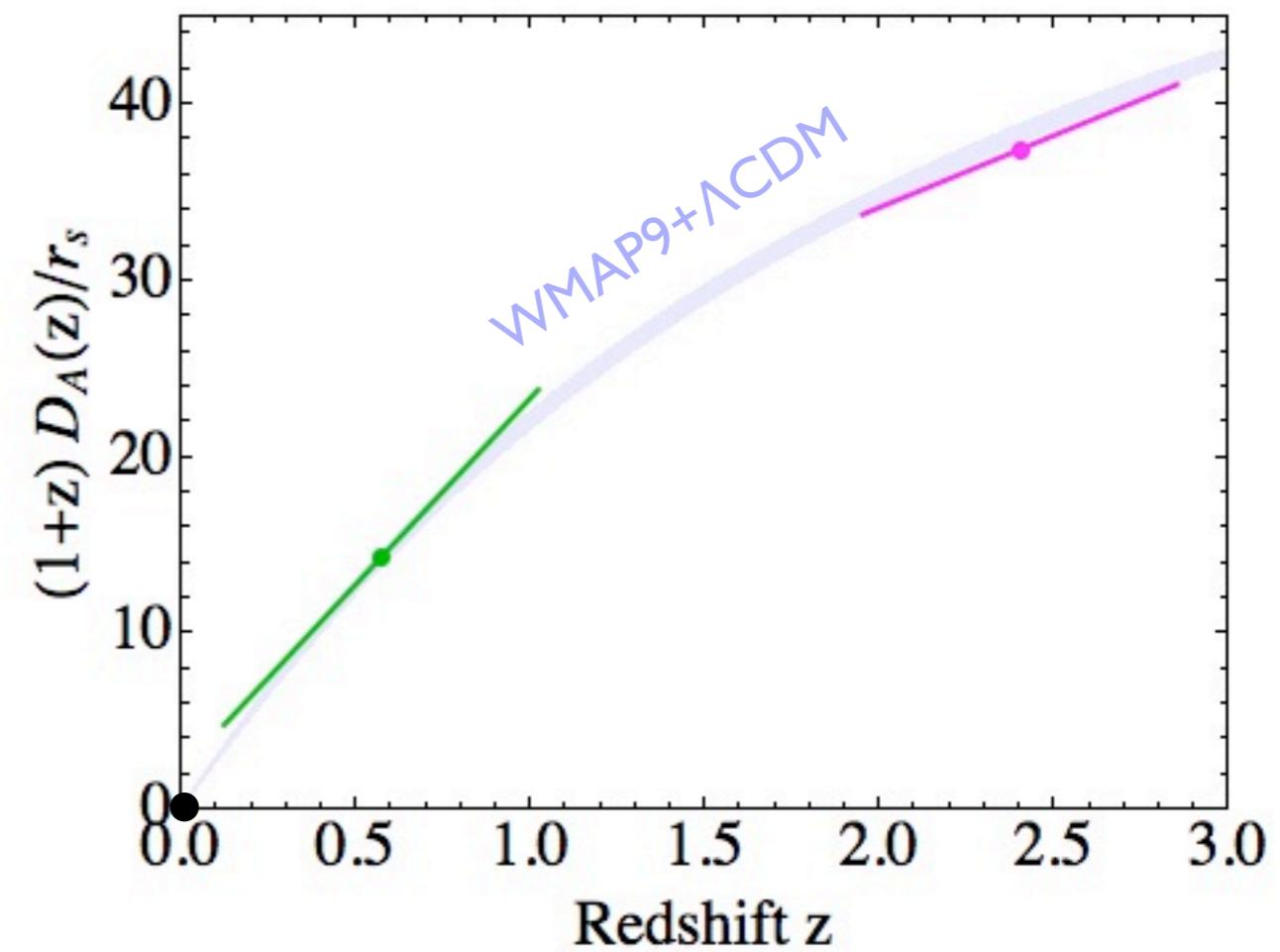
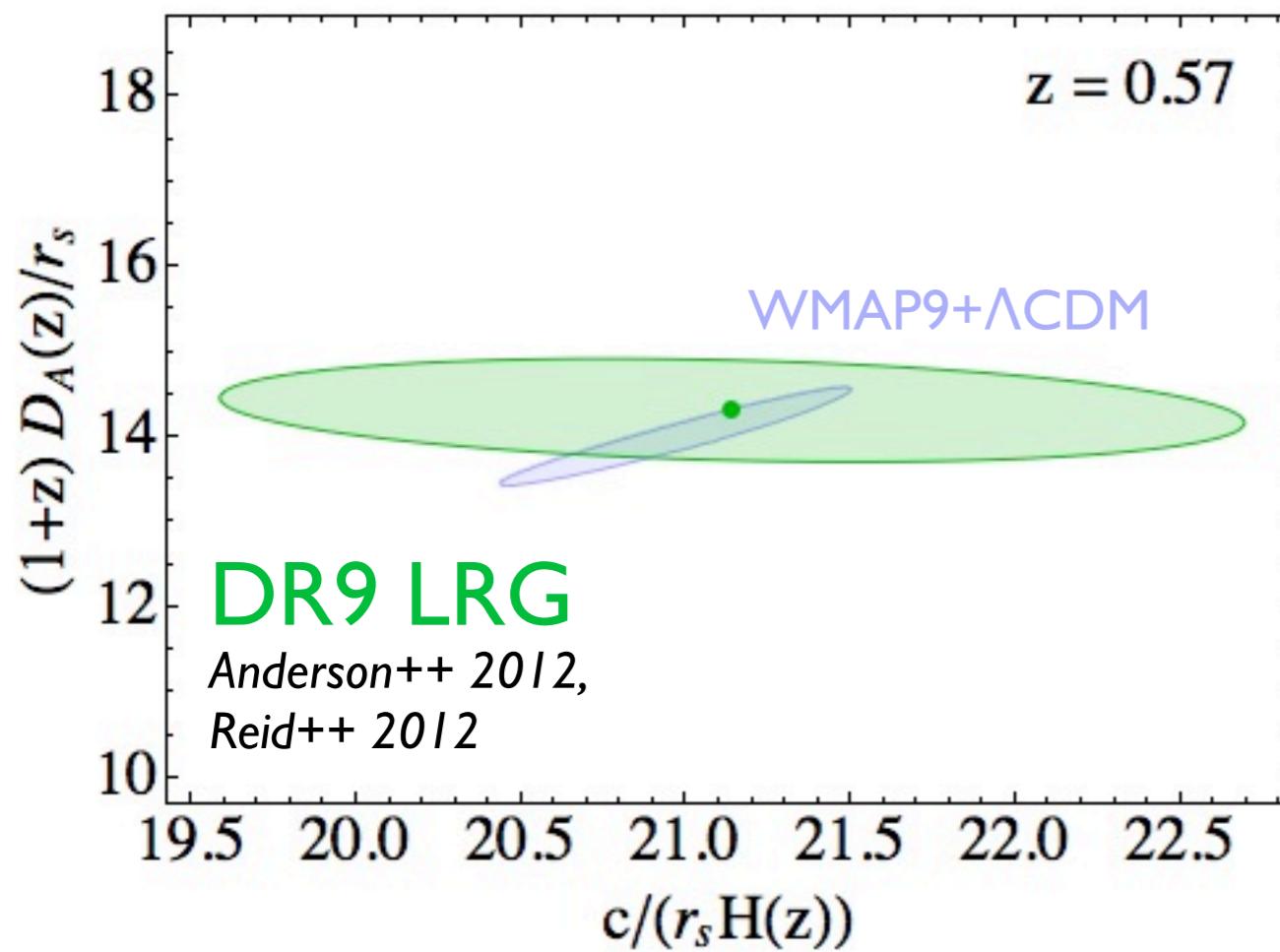
**decelerating  
expansion**

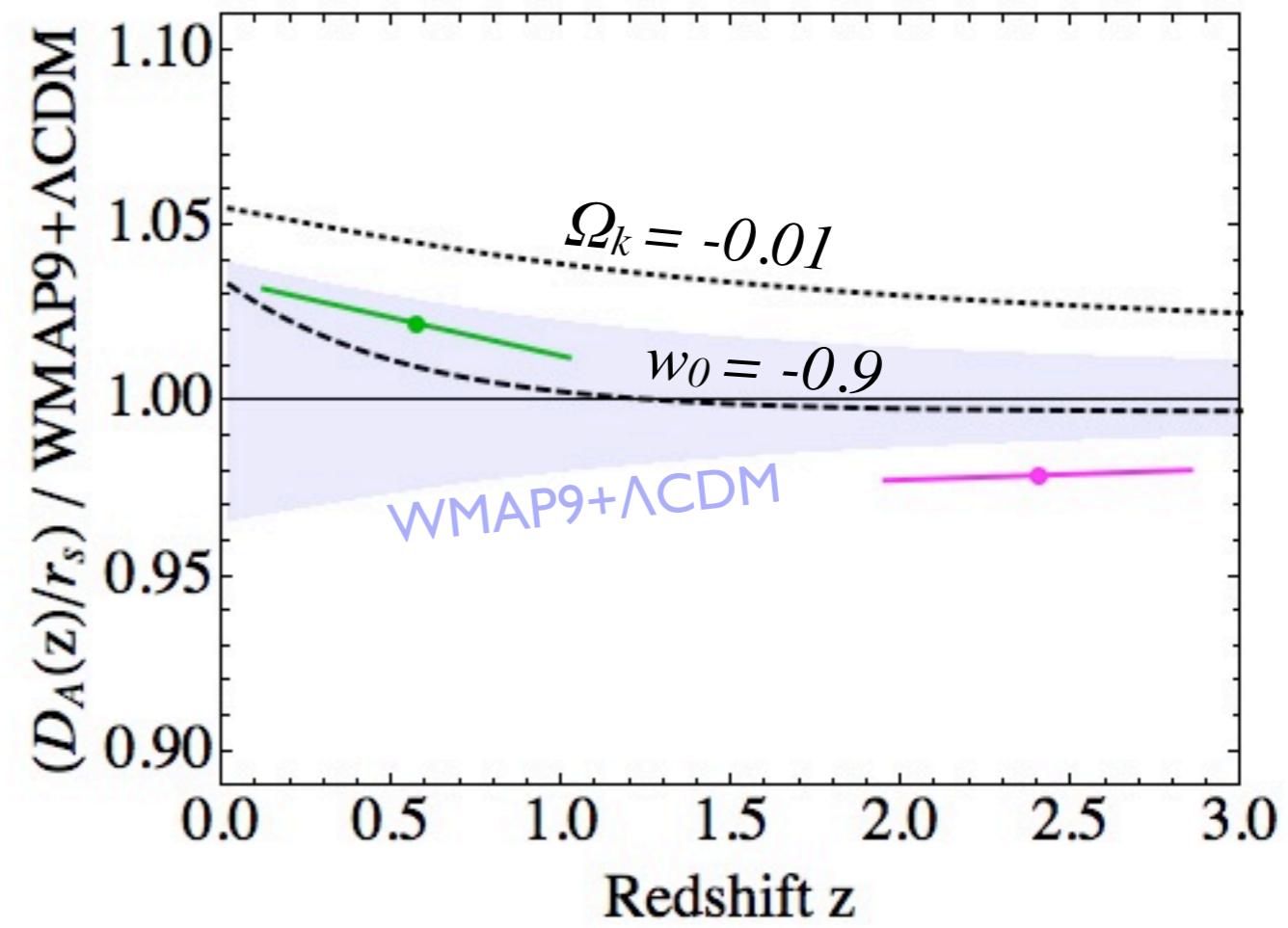
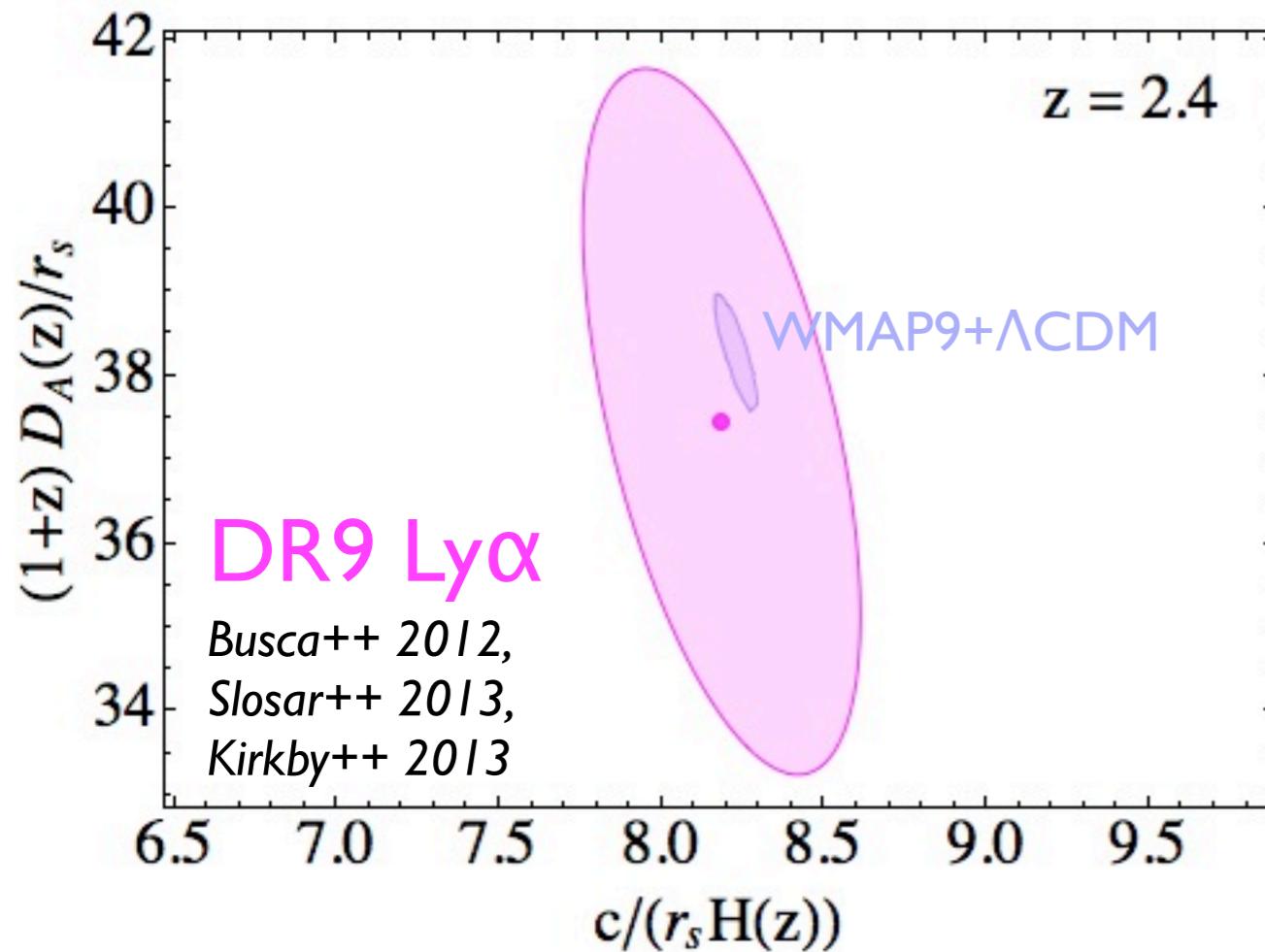
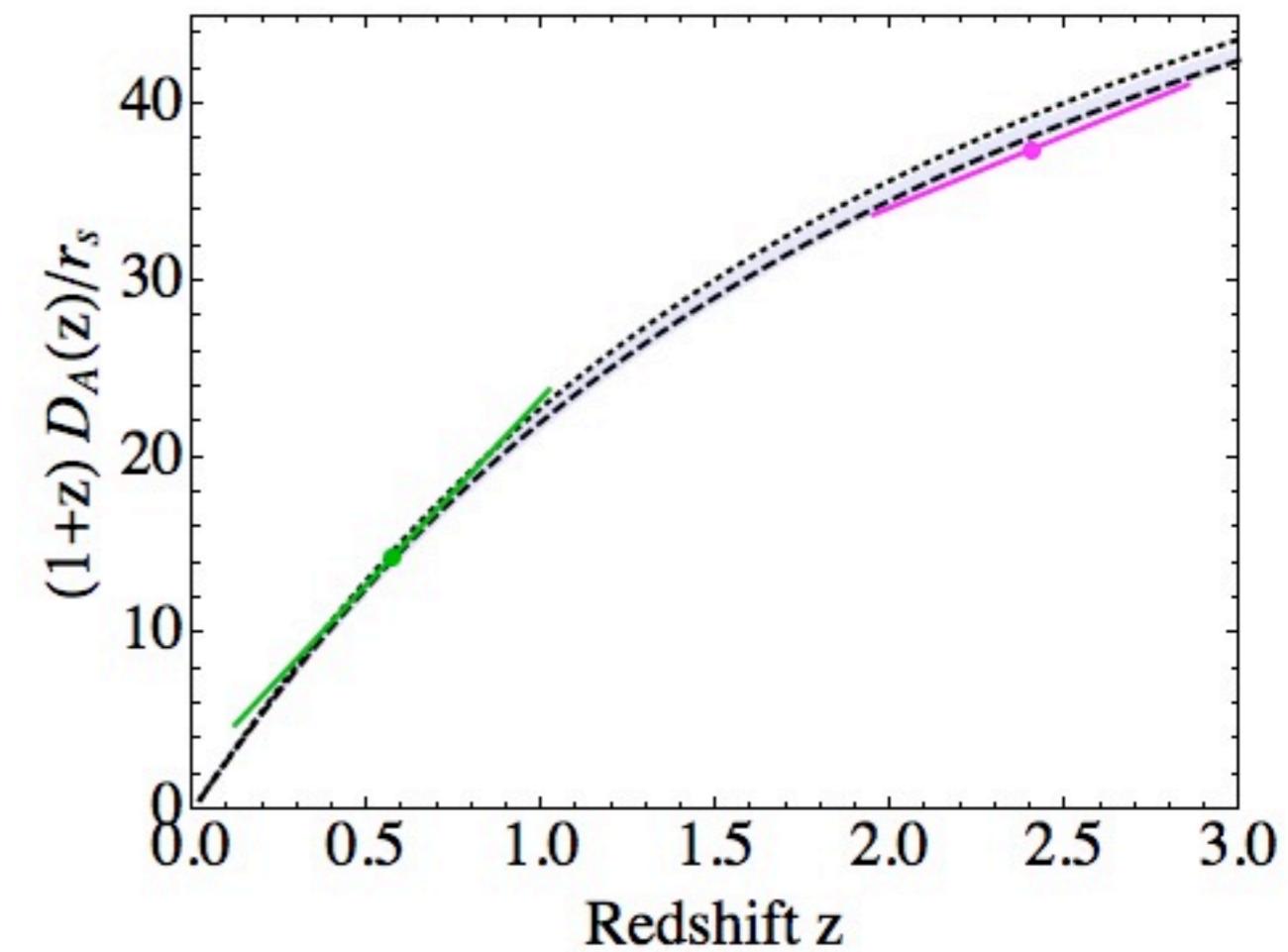
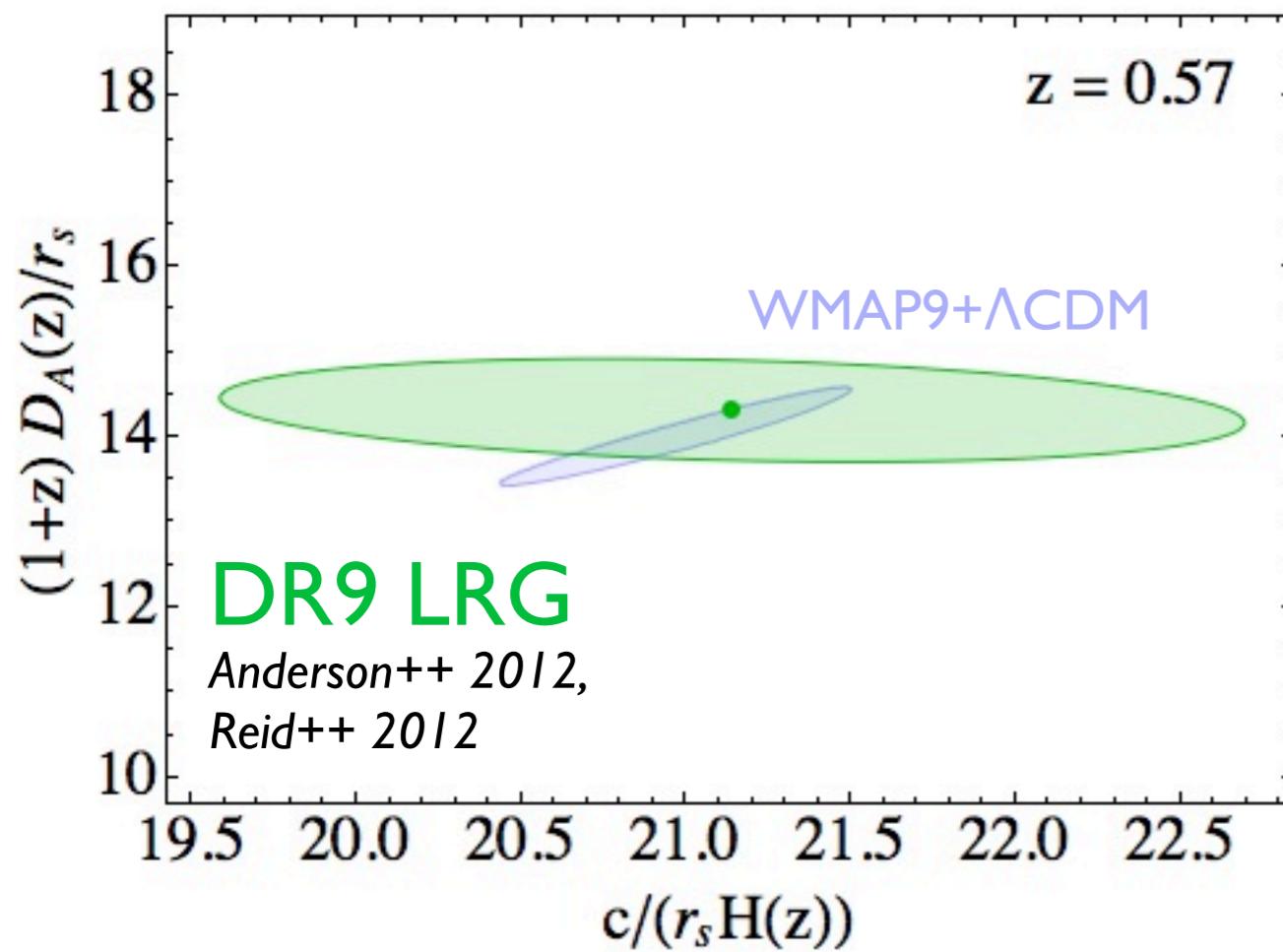
# Ly $\alpha$ F probes decelerating universe!

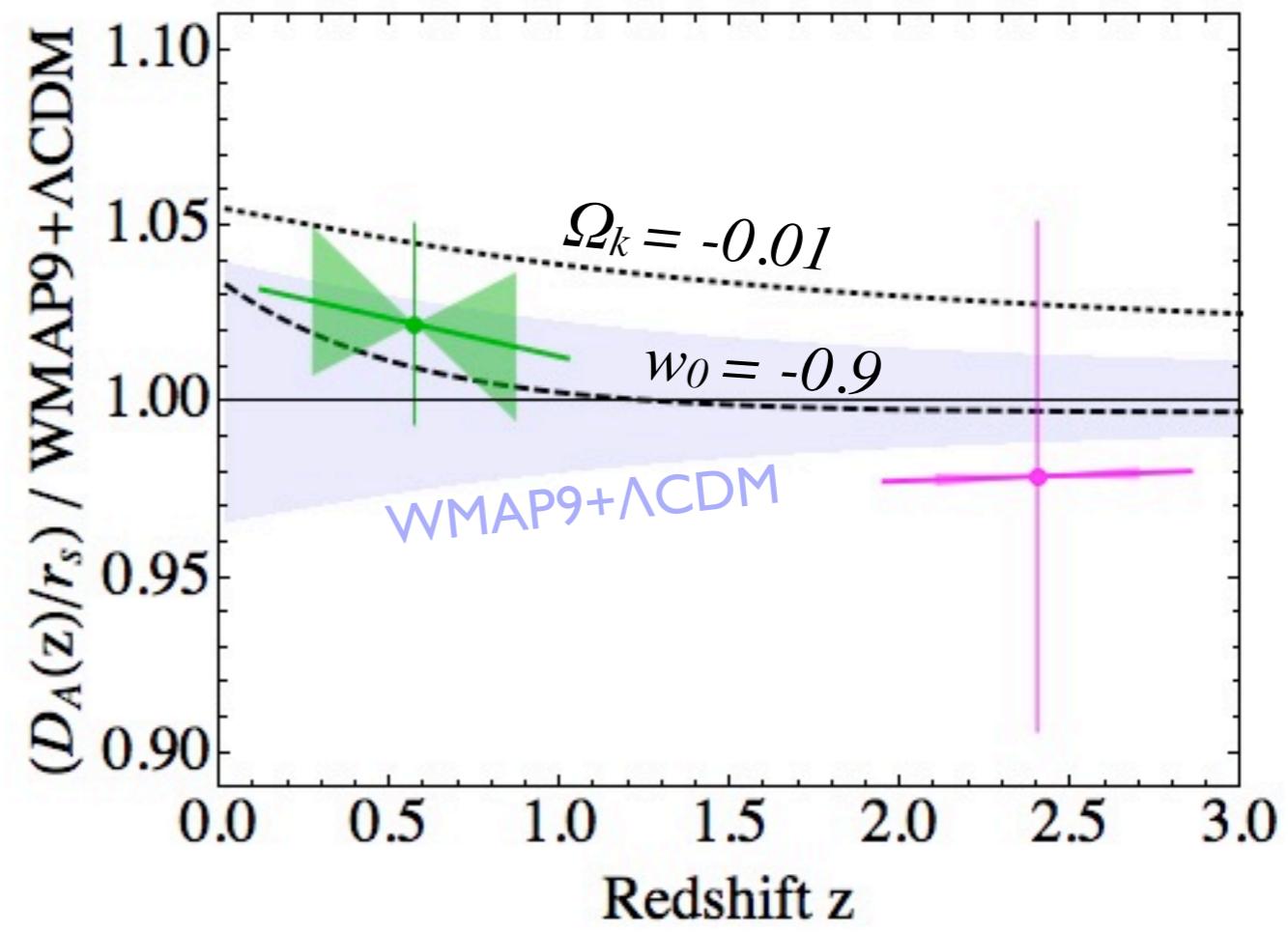
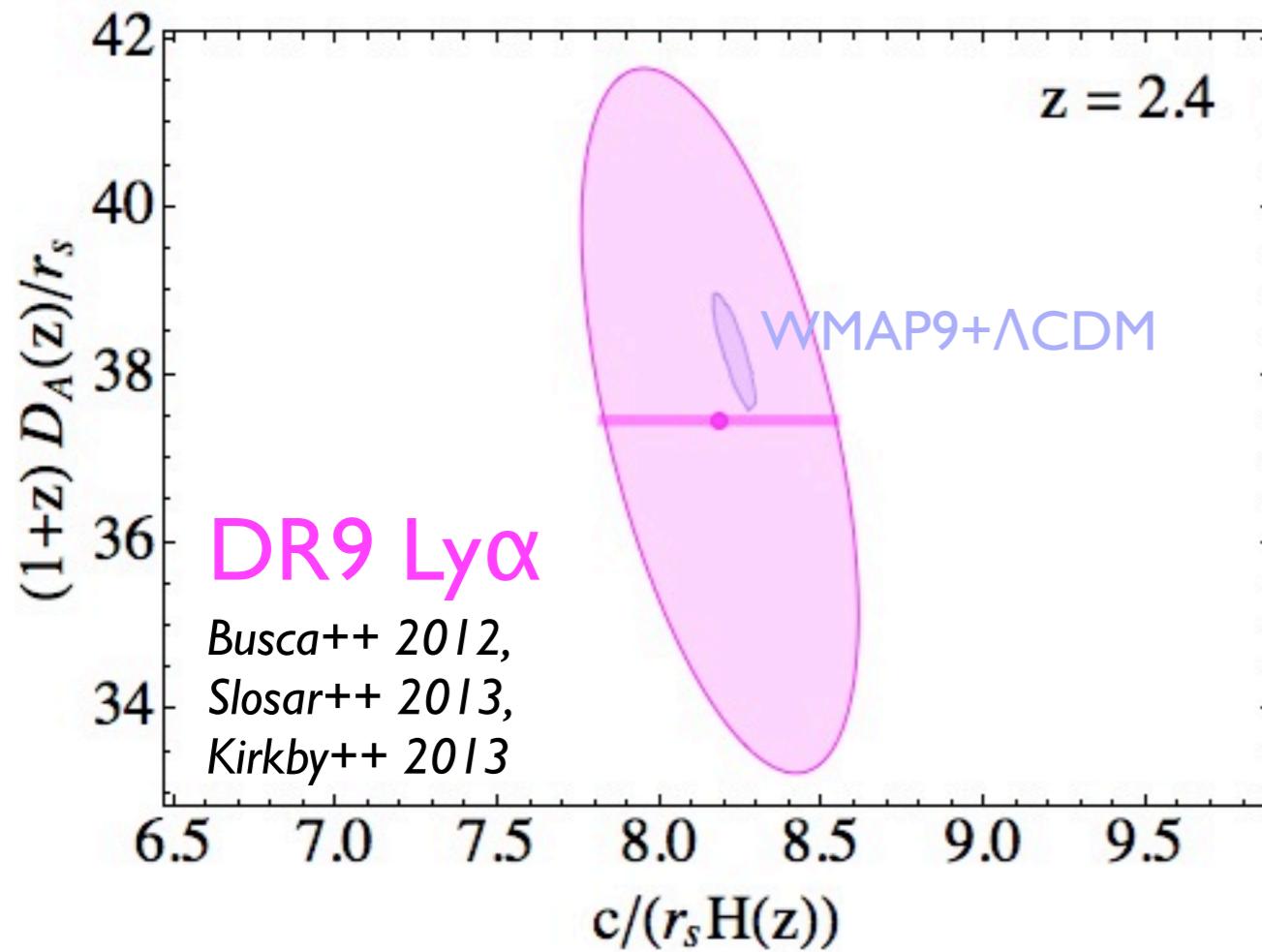
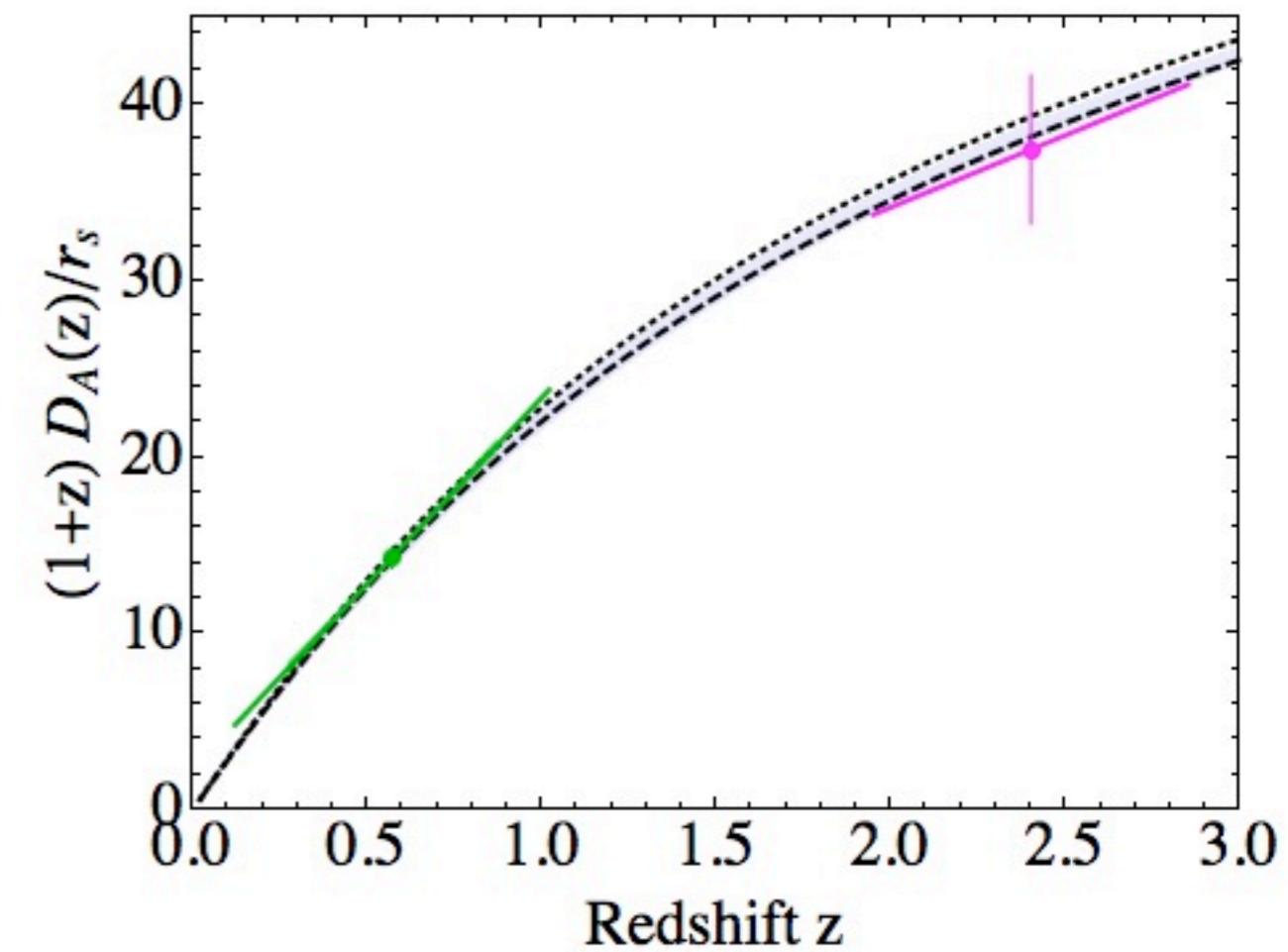
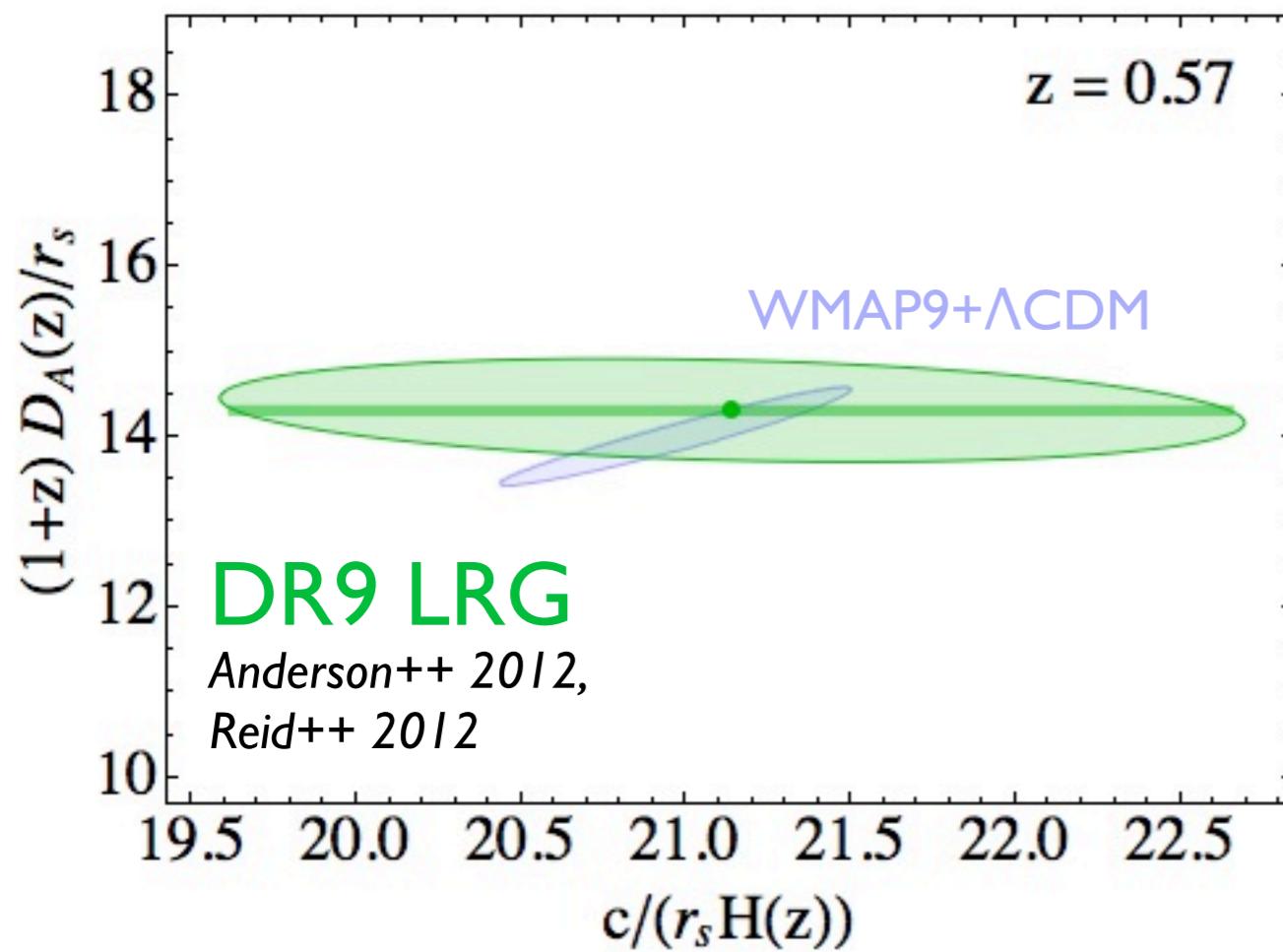


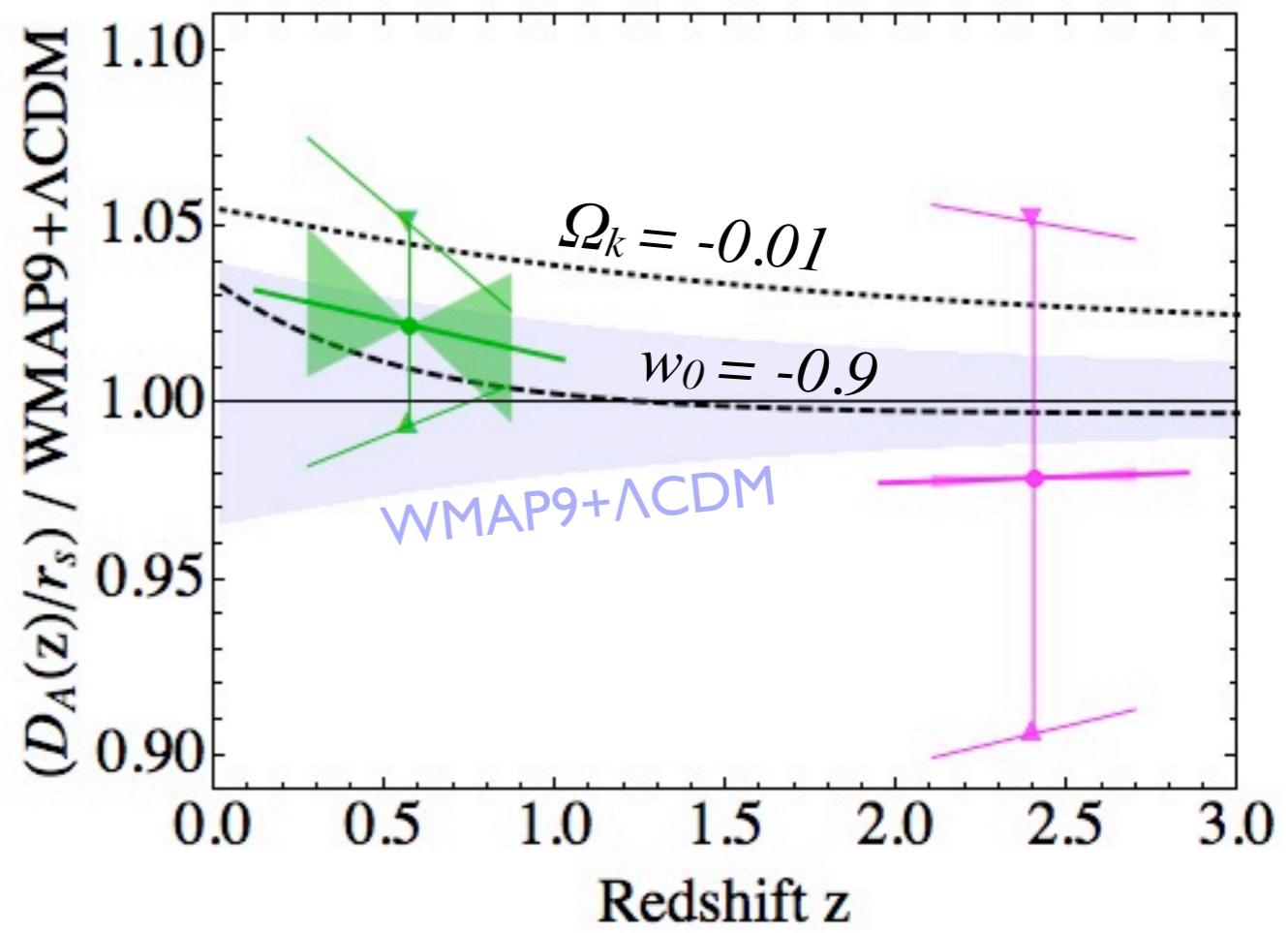
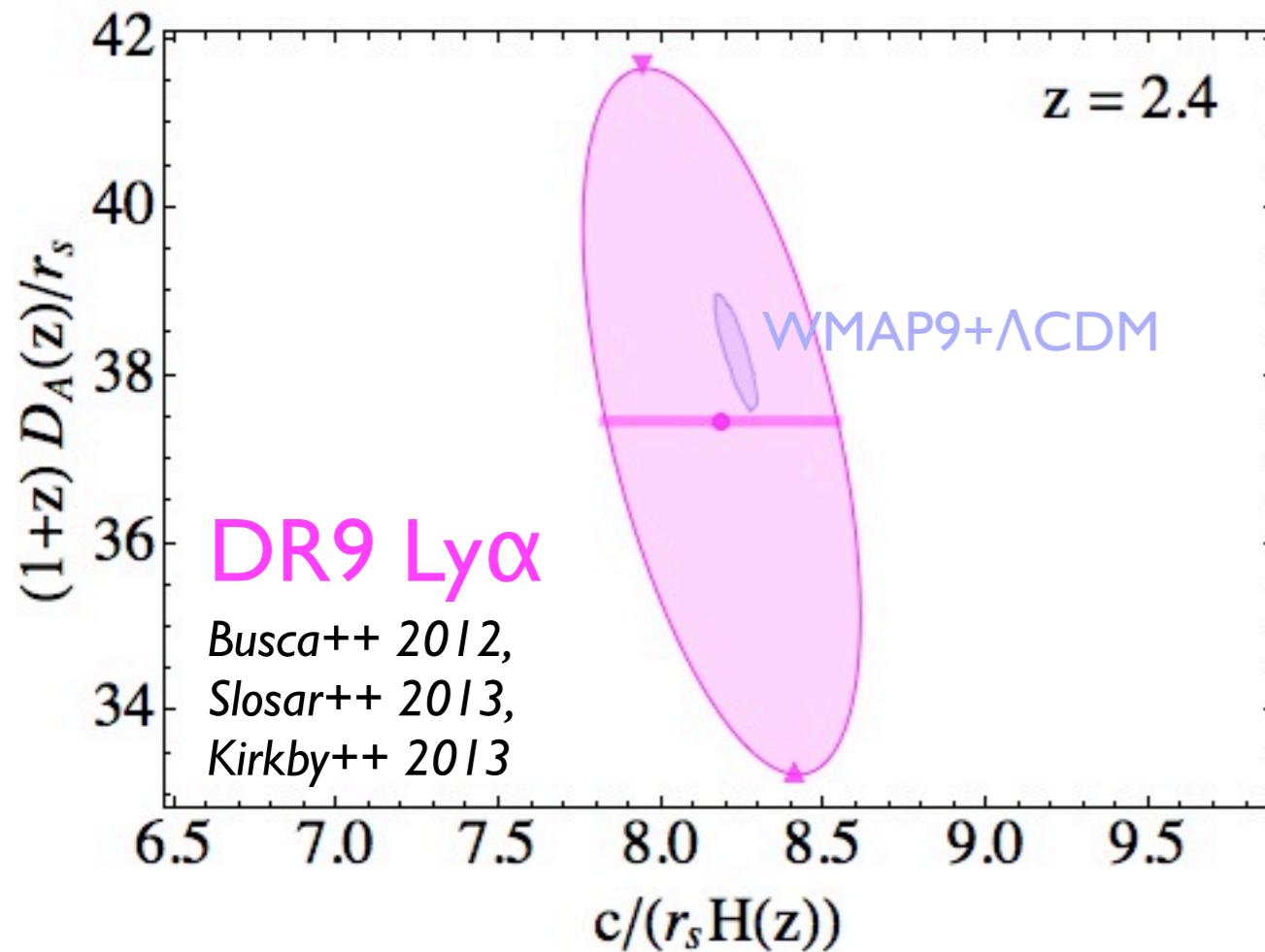
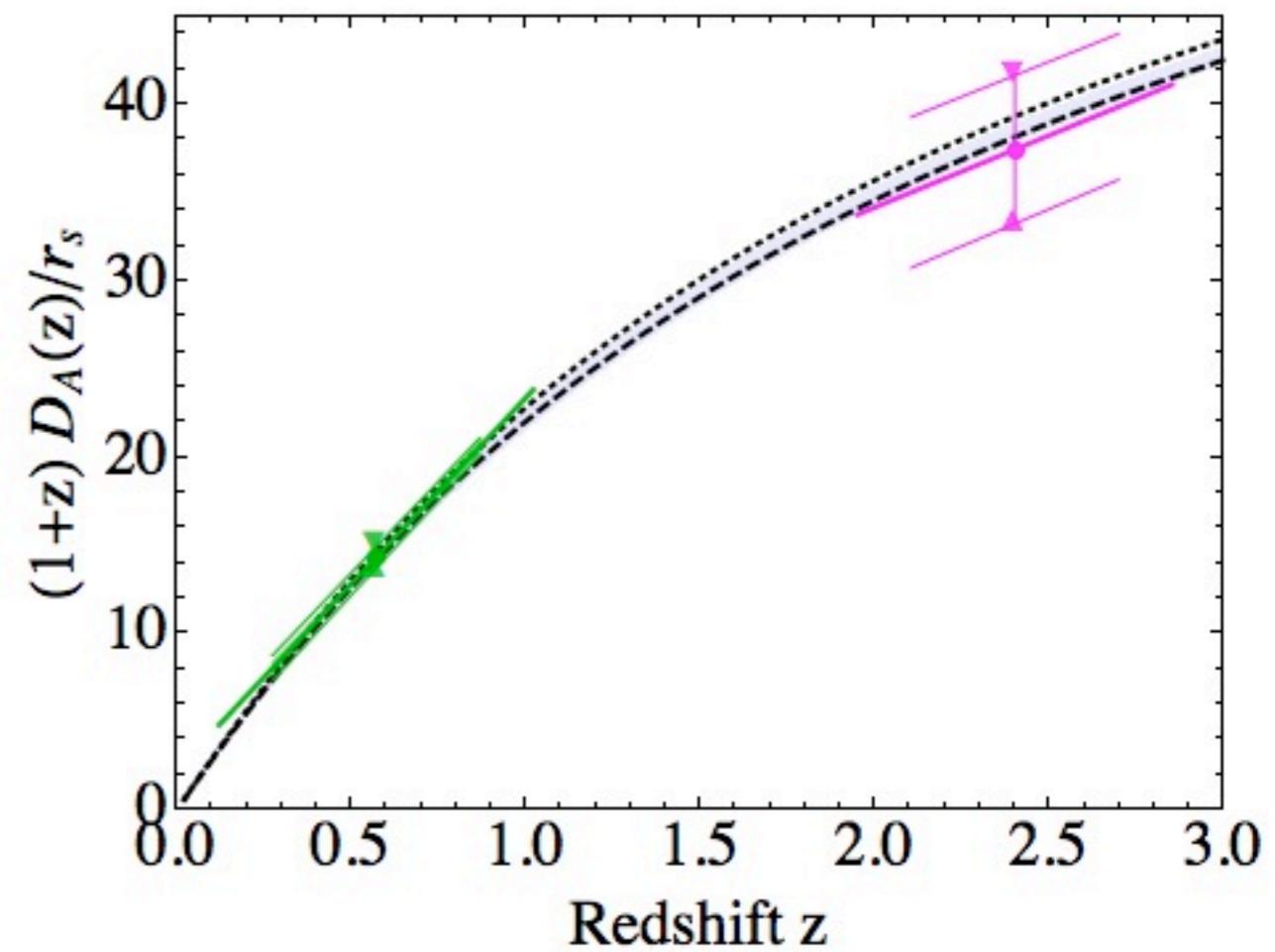
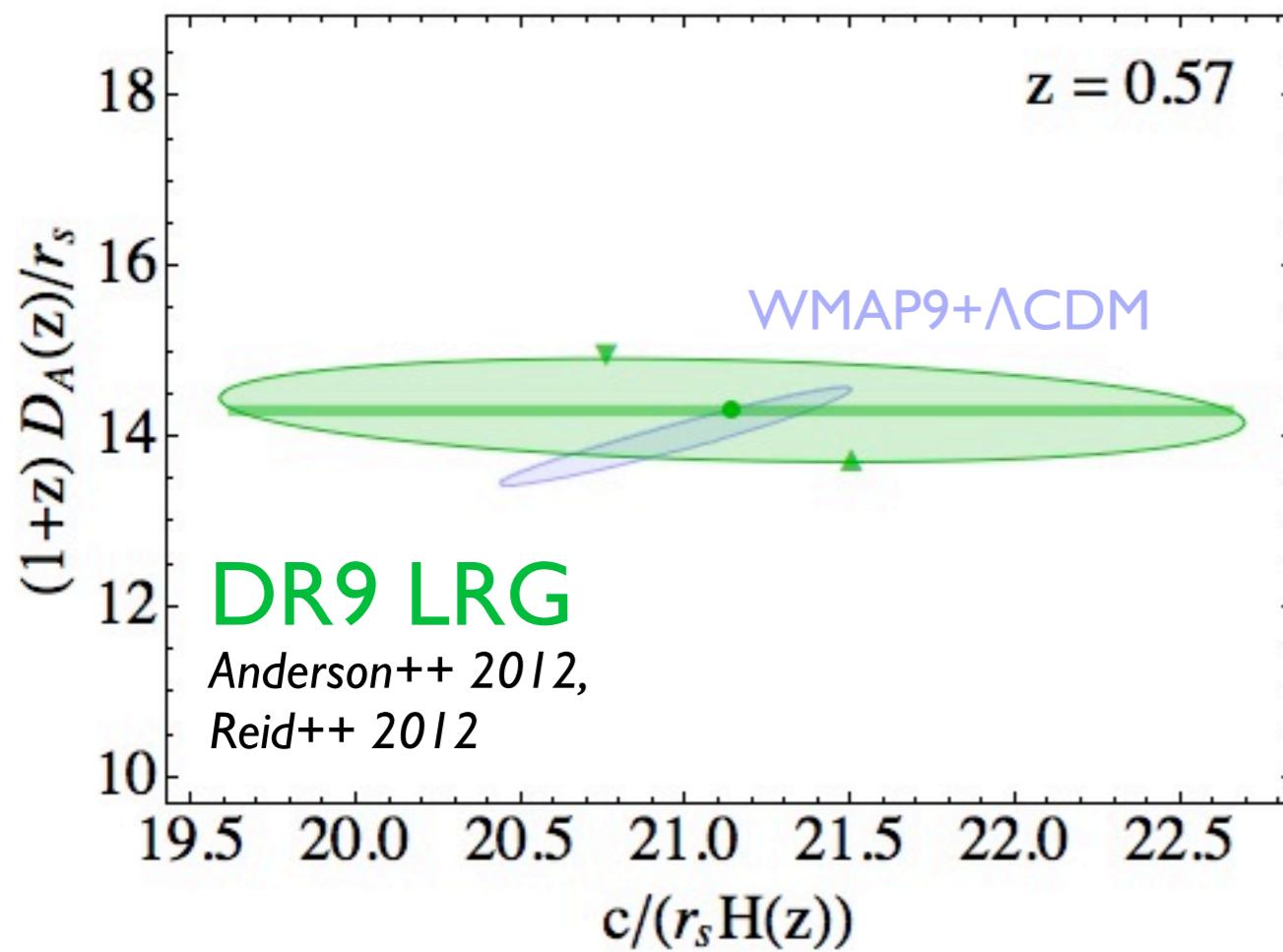












# Conclusions

BOSS working well and delivering on key projects.

BOSS BAO results consistent with  $\Lambda$ CDM.

Lyman- $\alpha$  forest now proven technique for BAO  
(but still challenging...)

Data collected during 2011-12 doubles DR9, and  
is being analyzed now (DR10 public Jul 2013).

Looking forward to MS-DESI !